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ORDNANCE EXPLOSIVE TRAIN DESIGNERS' HANDBOOK

APRIL 1952

LIST OF CONTRIBUTORS

The contributors to this handbook are or have been members of the Naval Ordnance Laboratory Staff unless otherwise indicated.

Chapter	Title	Authors
1	Introduction	H. J. Plumley.
2	Characteristics of Explosive Train Materials.	J. P. Wintermoyer. A. E. Robertson.
3	Characteristics of Primers	G. U. Graff. I. Kabik. E. F. Ward.
4	Characteristics of Detonators	G. U. Graff. I. Kabik.
5	Characteristics of Delays and Delay Elements.	W. S. Donahue. L. R. Butler. R. H. Comyn.
6	Characteristics of Leads	R. H. Blair.
7	Characteristics of Boosters	L. C. Smith E. H. Eyster. S. H. Wheatley.
8	Interaction of Explosive Train Components.	R. H. Stresau. A. E. Robertson.
9	Measurement Techniques	F. W. Hayward.
10	Loading	H. H. Moore. G. U. Graff. H. G. Wilson.*

*Naval Ordnance Test Station, China Lake, Calif.

PREFACE

The purpose of this handbook is to bring together in concise form the principles in the art and the science of explosive train design. There has been no primary source of these data, as they have been scattered among a large number of sources, including letters, specifications, and private notebooks.

In the last 20 years many individuals have concerned themselves with ordnance design. During World War II certain scientists, particularly physicists and physical chemists, became interested in the science of the initiation of explosives and conducted valuable experiments both theoretical and specifically pertaining to ordnance. These data, as well as fundamental facts which have long been known, are presented in this handbook.

Where possible, an attempt has been made to establish a connection between the art and the science. It will become obvious that the art has the advantage of a great head start over the science. For instance, the properties and preparation of mercury fulminate have been known since the year 1800; for certain ordnance purposes this material has not been supplanted during the last century and a half.

A further purpose of this volume is to uncover serious gaps in the art as well as the science of explosive train design. The gaps will become obvious in perusal of the book, since it will be noticed that the material in various spots will fall short of the assigned goal of a complete description of design principles.

It is hoped that by use of this handbook the design work of those already acquainted with the field will be facilitated and improved by allowing the designer to review the entire art in one package. Further, this handbook is intended to help the newcomer to the field to accomplish design work with a minimum of false starts.

The contributors to this handbook are indebted to the Bureau of Ordnance for financial support. The list of acknowledgments of helpful advice and criticism would include the following names: S. W. Booth, R. J. Burke, A. H. Erickson, R. L. Graumann, A. Lightbody, and D. E. Sanford, all of the Naval Ordnance Laboratory staff: and N. A. MacLeod, of Old and Barnes, Inc., Pasadena, Calif.

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Chapter 1

INTRODUCTION

Problems of Explosive-loaded Ordnance

On April 24, 1862, Gen. D. H. Hill of the Confederate Army wrote the following blunt note to his Secretary of War concerning certain problems he was having with the explosive trains of his day. "There must be something very rotten in the Ordnance Department. It is a Yankee concern throughout and I have long been afraid that there was foul play there. Our shells burst at the mouth of the gun or do not burst at all."

One year later at the Battle of Chancellorsville, an artillery chief reported that on the basis of careful observation only one out of every fifteen of the shells that were fired exploded at all. "I was compelled to watch closely the effect of all of the projectiles," he said, "as if we were using entirely solid shot."

By 1905, performance of ammunition had been somewhat improved; however, in the most significant naval engagement of the Russo-Japanese war in that year, namely the Battle of Tsushima, it is reported that one of the most important factors leading to the utter defeat of the Russian Fleet at the hands of the Japanese was the failure of the Russian fuzes to explode the projectiles.

To bring the story up to the present, it can be stated that the functioning of explosive loaded ordnance is in general quite satisfactory. Taking, for example, antiaircraft ammunition, Admiral Hussey, in forwarding to the Undersecretary of the Navy in 1945 a recommendation that a Navy fuze designer be given a special commendation, stated "40mm ammunition which was produced to the extent of 250 million rounds during World War II, functioned better than 99 percent in ballistic tests."

Rounds of ammunition of all categories, perfect in all respects, were, however, still unavailable in World War II. Much in particular remains to be accomplished in developing explosive trains capable of withstanding severe surveillance conditions. Following the bombardments of certain atolls in the Pacific by U. S. Naval Units, it was in some instances disconcerting to note that not all of the ammunition was used to maximum effectiveness. In "Comments on Amphibious Operations" dated 1 March 1944, the following statement appears: "The next disturbing type of malfunction was the duds and low order detonations noted on all the islands. While the number of duds found was large, it is not alarming considering the quantity of fire delivered."

From the examples cited, it is evident that the problems of explosive loaded ordnance are of long standing. The solutions to such of these problems as involve the explosive train are the province of this book. Actually the art (and the term is used advisedly) of explosive train design is in a well-advanced stage at the present time. Not only have the on-target performance records been raised in most cases to figures above 90 percent, but in addition the safety records of ordnance have been greatly improved. For instance, during World War I, ammunition that gave no more than one bore premature in twenty thousand rounds of firing was considered to be about as good as could be expected. In World War II with, for example, 5"/38 base-fuzed ammunition, bore prematures occurred at the rate of less than one in one million rounds.

Scope of This Handbook

Ordnance design is a field of broad extent, and in it the unwary author is likely to wander far afield unless he marks out for himself a sharply defined domain. This handbook covers explosive trains as applied to the entire field of explosive loaded ordnance. In every case, the discussion is limited to the explosive trains. For instance, there is no discussion of the sources of energy, either electrical or mechanical, which serve to trigger the fuze of an explosive loaded round. There is a detailed discussion of the manner in which the sensitivity of a stab primer is affected by the weight and velocity of the firing pin. There is no discussion of the details of the mechanism which moves a shutter containing a detonator to arm or disarm a round; but there is a detailed discussion of the way in which the probability of firing the subsequent element in the train is modified as a function of the amount of dislocation of the detonator or of interposition of air gaps.

The explosive train designs treated in this book are applicable primarily to bomb and projectile fuzes. However, the same basic principles may be applied to a wide range of explosive loaded ordnance items. The following list of such items is not necessarily complete.

- Gun launched projectiles of all calibers.
- Rocket projectiles.
- Bombs.
- Underwater ordnance such as mines, torpedoes, and depth charges.
- Projectiles of advanced designs, including self-propelled and guided missiles.

Description of a Complete Explosive Train

A short over-all description of the explosive train of Base Fuze Mk 21 for major caliber projectiles is presented here in order to give the newcomer to this field a comprehensive view which he might not

otherwise obtain by reading the detailed discussions of the various components which appear later. The function of this fuze is to initiate, following a delay of 0.035 second after impact with steel armor plate, a high-order explosion in the filler of projectiles from 6 to 16 inches in diameter. A cross section of Base Fuze Mk 21 is shown in figures 1–1 and 1–2. In this short description, attention is centered on the explosive train and the mechanical features of the fuze functioning are touched upon only lightly. The central axial assembly of the fuze, which is mounted on ball races, moves forward on plate impact against the **anticreep spring**, causing the **stab primer** to impinge on the **firing pin.** (See figs. 1–1 and 1–2.)

The **stab primer**, designed for maximum sensitivity to initiation on impact with this type of firing pin, is loaded with a priming composition consisting of a mixture of basic lead styphnate ($C_6H(NO_2)_3(OPbOH)_2$), antimony trisulfide (Sb_2S_3), barium nitrate ($Ba(NO_3)_2$), tetracene ($C_2N_{10}H_8O$), and lead azide (PbN_6); the explosion of this mixture forces the **delay element primer firing pin** into the **delay element primer.**

This primer is loaded with a priming mixture similar to that used in the stab primer except that it does not contain lead azide. It differs from the stab primer in two respects; firstly, its housing is stronger and is not punctured during actuation, a characteristic which makes possible maintenance of a gas seal on the next element, the **delay pellet**, and secondly, it is inherently less sensitive to impact than the stab primer.

The hot gases from the percussion primer permeate through the **baffle** and initiate the black powder **delay pellet**, which burns, under the reproducible pressure conditions which obtain within the delay housing, with a delay time of 0.035 second. When the black powder element has burned through, a spit of flame impinges on a lead azide-loaded **detonator**; a true detonation develops and progresses successively through the tetryl-loaded **lead out**, the tetryl-loaded **booster lead in**, the tetryl-loaded **booster**, and the **main charge** of the shell, explosive D (ammonium picrate).

Certain general remarks may be made concerning this explosive train, which hold in general for any train. As one proceeds down the train, the size of the elements in general increases while their sensitivity to initiation decreases. For instance, in decreasing order of sensitivity we have:

(*a*) Priming mixture.
(*b*) Lead azide.
(*c*) Tetryl.
(*d*) Explosive D.

As implied in the word "train," each element has two ends and

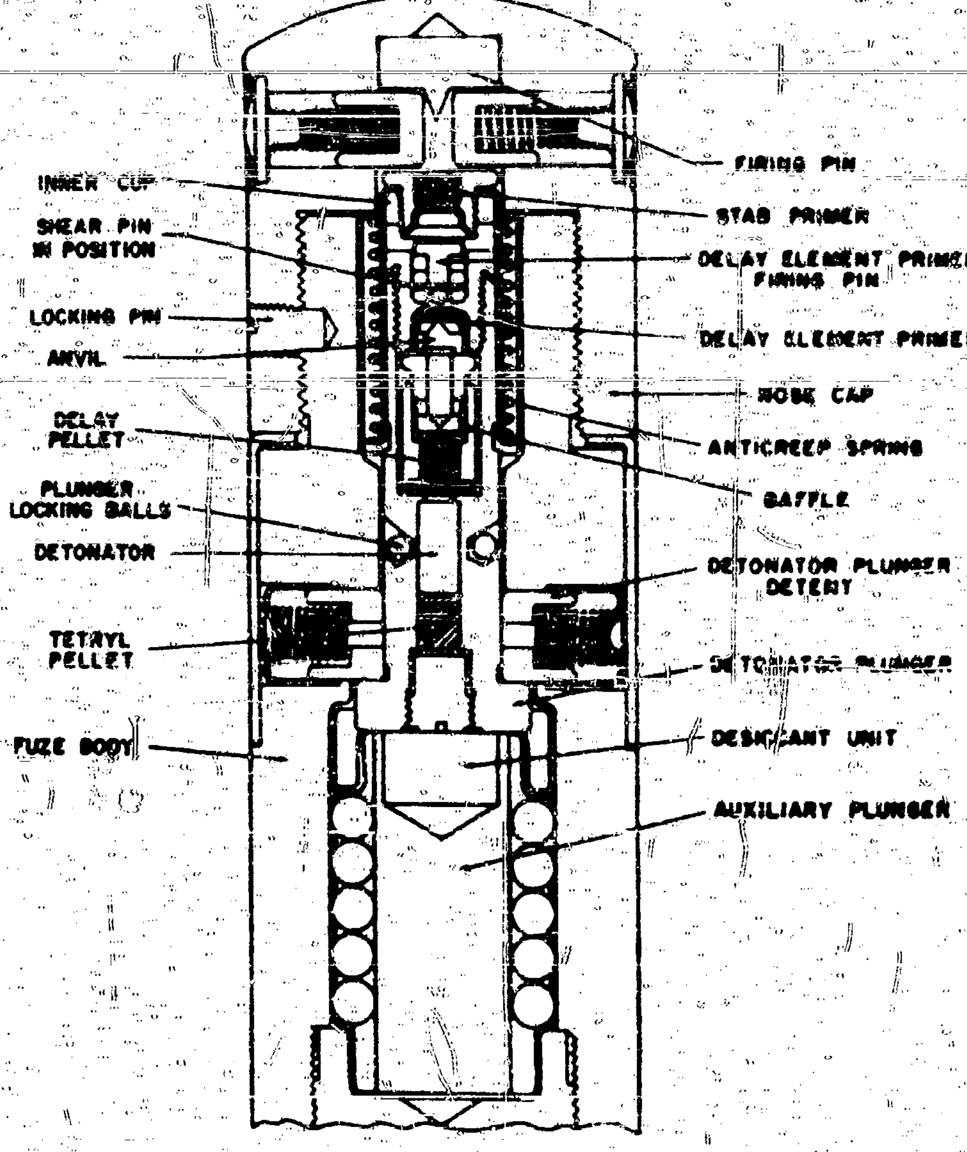

Figure 1-1. Base Fuze Mk 21, Assembled Position. Sectional View.

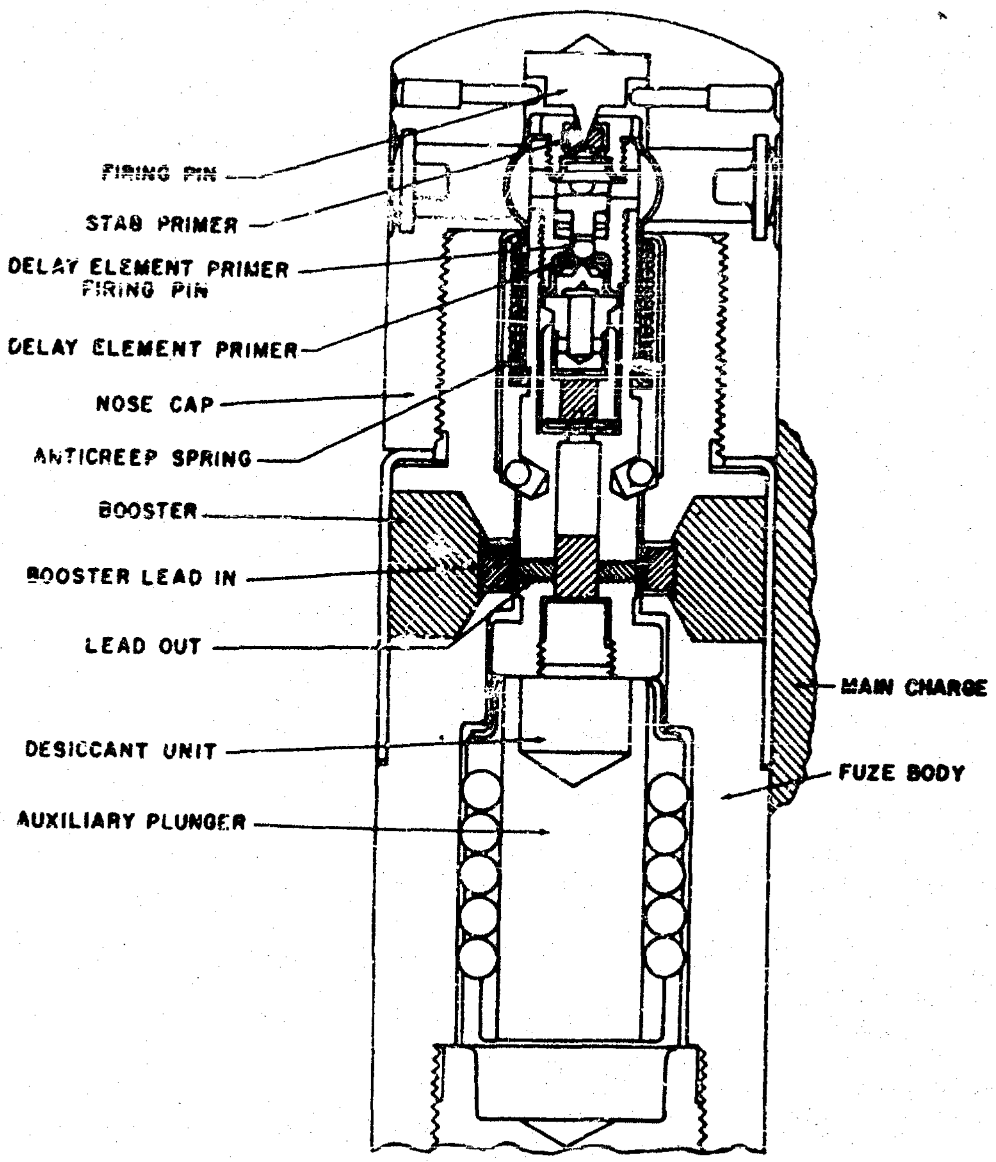

Figure 1–2. Base Fuze Mk 21, Firing Position. Sectional View.

concomitant with this fact has two characteristics, an input characteristic and an output characteristic. We characterize, for instance, the percussion primer with regard to its input characteristic by its drop weight sensitivity, and with regard to its output characteristic by the number of calories of heat which it develops on deflagration and which appear in its output flame. The lead azide detonator is characterized on its input end by its flame sensitivity (as measured, for instance, in the oxy-hydrogen bomb apparatus described on page 9-16) and on its output end by the peak pressure developed at its detonation front where it contacts the succeeding element in the train.

Chapter 2

CHARACTERISTICS OF EXPLOSIVE TRAIN MATERIALS

Explosive train materials have the common characteristic of being capable of reacting, when properly initiated, with the evolution of considerable energy. This reaction does not depend on the availability of any outside material such as oxygen; hence, the reaction can be made to occur in hermetically sealed components.

The materials used in explosive trains may, for convenience of discussion, be divided into explosives and delay materials. Explosives, in general, react more rapidly than do delay materials; however, in the case of short delays the difference in reaction rate tends to disappear, and in some cases a single material may be made to serve both purposes.

From the standpoint of composition, explosive train materials consist of an oxidant (oxidizing material) and a fuel (oxidizable material), held in intimate contact in a metastable condition. Delay materials usually consist of mechanical mixtures of oxidants and fuels, in the form of fine powders. In the case of explosives, the oxidant and fuel are usually incorporated into a single molecule, so that explosives are normally homogenous materials. There are numerous exceptions to the above generalizations, since a pure explosive compound may be used as a delay material, while explosives may consist of mechanical mixtures of explosive compounds and/or oxidizing and reducing chemicals. Other materials may be added to impart special characteristics; for example, wax may be added to a high explosive to decrease its sensitivity.

Section 1.—Explosives

An explosive may be defined as a metastable substance which, if activated by an external source of heat or shock, decomposes spontaneously to produce a large amount of energy. Results of this decomposition are the sudden production of a large volume of reaction gases at high temperature and a sudden rise in pressure in the immediate vicinity. This transformation normally takes place in a period of the order of a few microseconds.

An explosive may be regarded as a material containing stored energy and capable of releasing that energy upon activation. From the standpoint of thermochemistry, the energy released is the difference between the heat of formation of the original explosive and the heat of formation of the products of reaction.

TABLE 2-1.—*Physical Properties of Primary Explosives*

[Reference numbers at heads of columns indicate sources of data]

Explosive	Formula	(7) Mol. weight	Color	(7) Crystal density	Melting point (degrees C)	Oxygen balance (percent)
Mercury Fulminate	$Hg(ONC)_2$	284.6	White to gray	4.4	Explodes	−11.2.
Lead Azide	PbN_6	291	White to gray	4.68 to 4.72	Explodes	
Lead Styphnate, normal	$C_6H(NO_2)_3O_2Pb$	450	Yellow to brown.	2.9 (anhyd.)	Explodes	−16 to −19.
Diazodinitrophenol (DDNP)	$C_6H_2(NO_2)_2ON_2$	210	Yellow to brown.	1.63 (at 25°)	Explodes	−61.
Tetracene	$H_2NC(=NH)-NHNHN=N-C(=NH)-NHNHNO$	188	Pale yellow		Explodes	−59.6.
Nitromannite (Mannitol-Hexanitrate).	$O_2NOCH_2(CHONO_2)_4CH_2ONO_2$	452	White		112 to 113	+7.1.

From the standpoint of use in explosive trains, it is convenient to divide explosives into three classes; primary explosives, priming mixtures, and high explosives.

Primary Explosives

The distinguishing characteristic of primary explosives is their extreme sensitivity to heat or shock. They are the most sensitive of the explosives and, either as pure materials or as ingredients of priming mixtures, they occupy the "starting" position in explosive trains.

Table 2–1 lists the more common primary explosives by their most widely accepted names. Tetracene and nitromannite are included in this group, although many of their characteristics are similar to those of the high explosives. Chemical and physical data are included in this table.

Oxygen balance is expressed in percent and represents the excess or deficiency of oxygen as compared to that required to convert the carbon to carbon dioxide and the hydrogen to water. Mathematically it is 100 times the weight (grams) of excess or deficient oxygen per gram mole of explosive divided by the molecular weight of the compound. This is a measure of the extent to which the molecule is deficient or overly rich in the amount of oxygen necessary for its complete decomposition.

Explosive characteristics given in Table 2–2 include the sensitivity and the strength, or power, of the explosive. The sensitivity to impact refers to the 50 percent explosion height obtained on the ERL

TABLE 2–2. *Explosive Characteristics of Primary Explosives*

[Reference numbers at heads of columns indicate sources of data]

Explosive	(2) Sensitivity to impact	(3) Sensitivity to friction	(8) Thermal properties (K Cal/Mole, 25° C)			(3) (7) Strength, sand test		
	Type 3 machine 50% explosion height (cm)	Max. added wt. for no. explosion/10 trials (gm)	Heat of combustion ($-H_c$)	Heat of formation ($-H_f$)	Heat of explosion ($-H_e$)	Loading pressure lb/sq. in.	Gms. sand finer than 30 mesh: 0.4 gm. charge	Gms. sand finer than 30 mesh: 1.0 gm. charge
Mercury Fulminate	12.0	25	....	−66.8	104.8 (39)	3,400	17.0	48.4
Lead Azide	15.0	1,000	....	−111.6	69.7 (39)	3,400	14.2	36.0
Lead Styphnate (Normal)	11.0	5,000	....	−92.3	....	....	....	....
Diazodinitrophenol	7.0	5,000	....	....	172.2	3,400	36.2	90.0
Tetracene	12.0	....	....	....	....	(1) 3,000	13.1 2.0	....
Nitromannite	8.0	....	670.9	+160.1	637.5	....	....	....

[1] Unconfined.

type 3, Drop-weight Impact Machine. This type of machine, applicable to the more sensitive explosives, is described in reference (2

Friction-sensitivity values were obtained on the Bureau of Mines Type B Pendulum Friction device described in reference (3). They represent the maximum weight (grams) added to the pendulum falling from a height of 50 cm. for which "no explosions" were obtained in 10 successive trials. A sample of 0.02 gram was used for each test.

Thermal properties. The values reported for heat of formation (H_f) and heat of explosion (H_e) were derived from measured values of the heat of combustion (H_c) (ref. (8)). The latter values were assumed to have been obtained in an oxygen bomb with the water formed in the reaction being condensed to the liquid state. In calculating the heat of explosion, it was assumed that no atmospheric oxygen was available and suitable corrections were applied in case of a deficiency of oxygen. The heat-of-explosion data were also calculated on the assumption that any water formed by the reaction would be present in the vapor state. In estimating the products formed by the explosion, the following assumptions were made:

(1) The nitrogen all appears as molecular N_2.

(2) The available oxygen is first used to oxidize the carbon to CO.

(3) Any oxygen remaining from (2) is used to oxidize the hydrogen to H_2O.

(4) Any oxygen left over from (3) is used to oxidize CO to CO_2.

Sand test. The strength of the explosives as determined by the sand test is expressed in grams of sand crushed finer than 30 mesh. The reported values were determined in the Bureau of Mines No. 2 sand-test bomb using a total of 200 grams of sand of a standard grade and quality. A definite weight of the explosive was pressed in a No. 8 detonator cup at a specified pressure. This procedure is described in reference (6).

Detonation velocities (meters/second) of mercury fulminate, lead azide, lead styphnate, and diazodinitrophenol at various loading densities are reported graphically in figures 2-1, 2-2, 2-3, and 2-4, respectively. Naval Ordnance Laboratory data presented in these figures were obtained on a column of the explosive, 0.150 inch in diameter by 3.0 inches long, initiated with a lead azide charge. Times were measured with a Potter Electronic Counter having a counting rate of 1.6 megacycles.

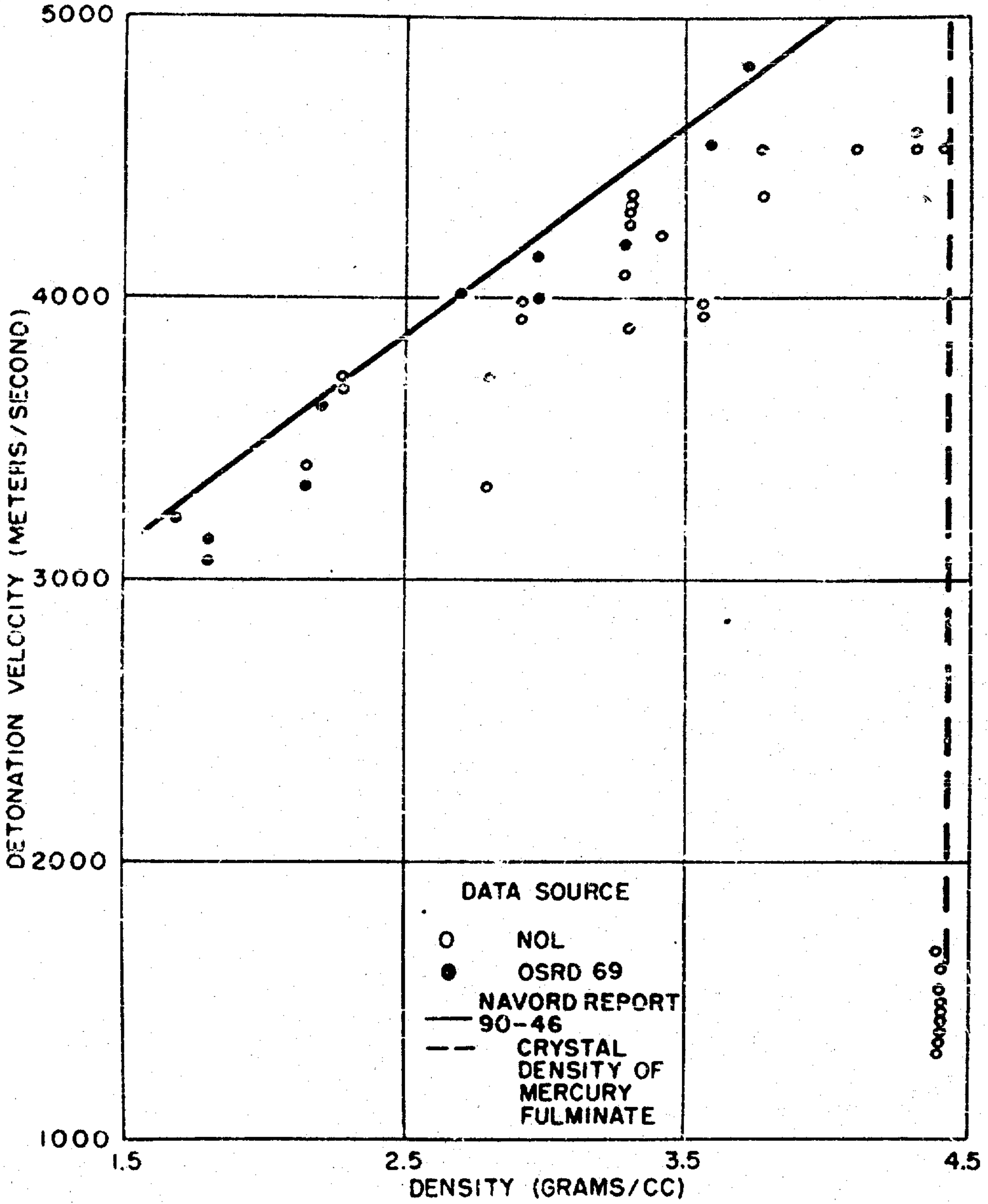

Figure 2-1. Mercury Fulminate, Density vs. Detonation Velocity.

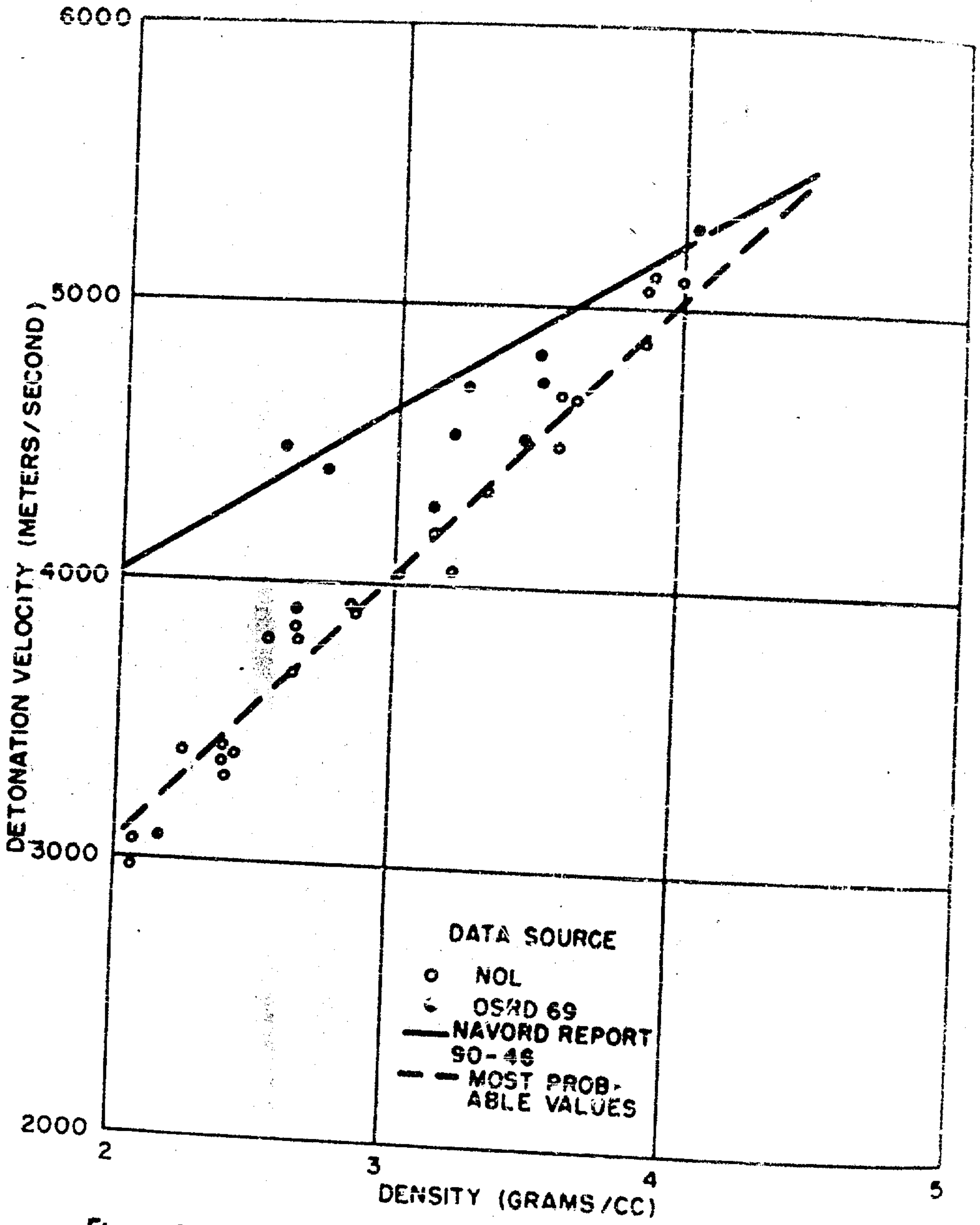

Figure 2–2. Lead Azide, Density vs. Detonation Velocity.

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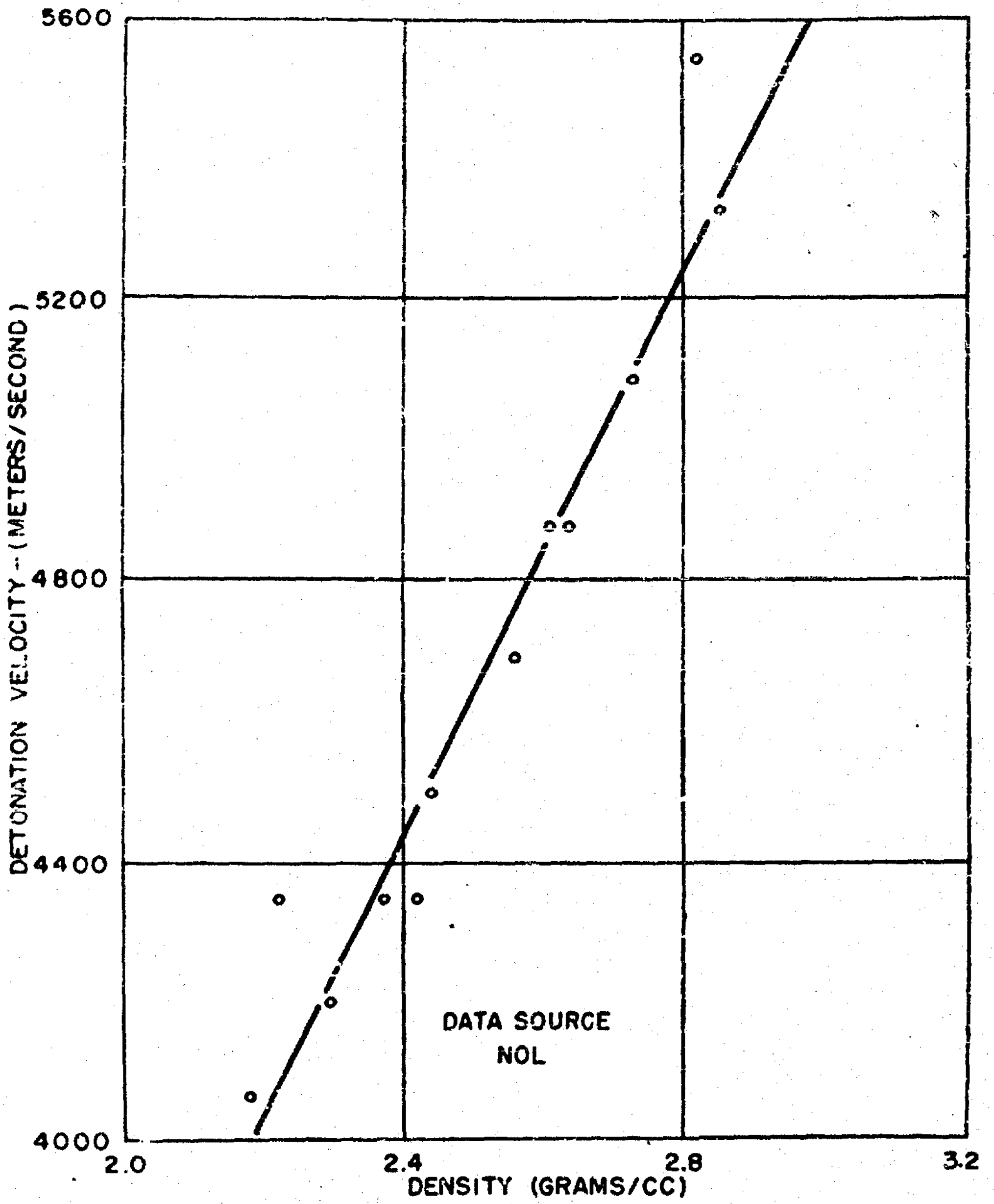

Figure 2-3. Lead Styphnate, Density vs. Detonation Velocity.

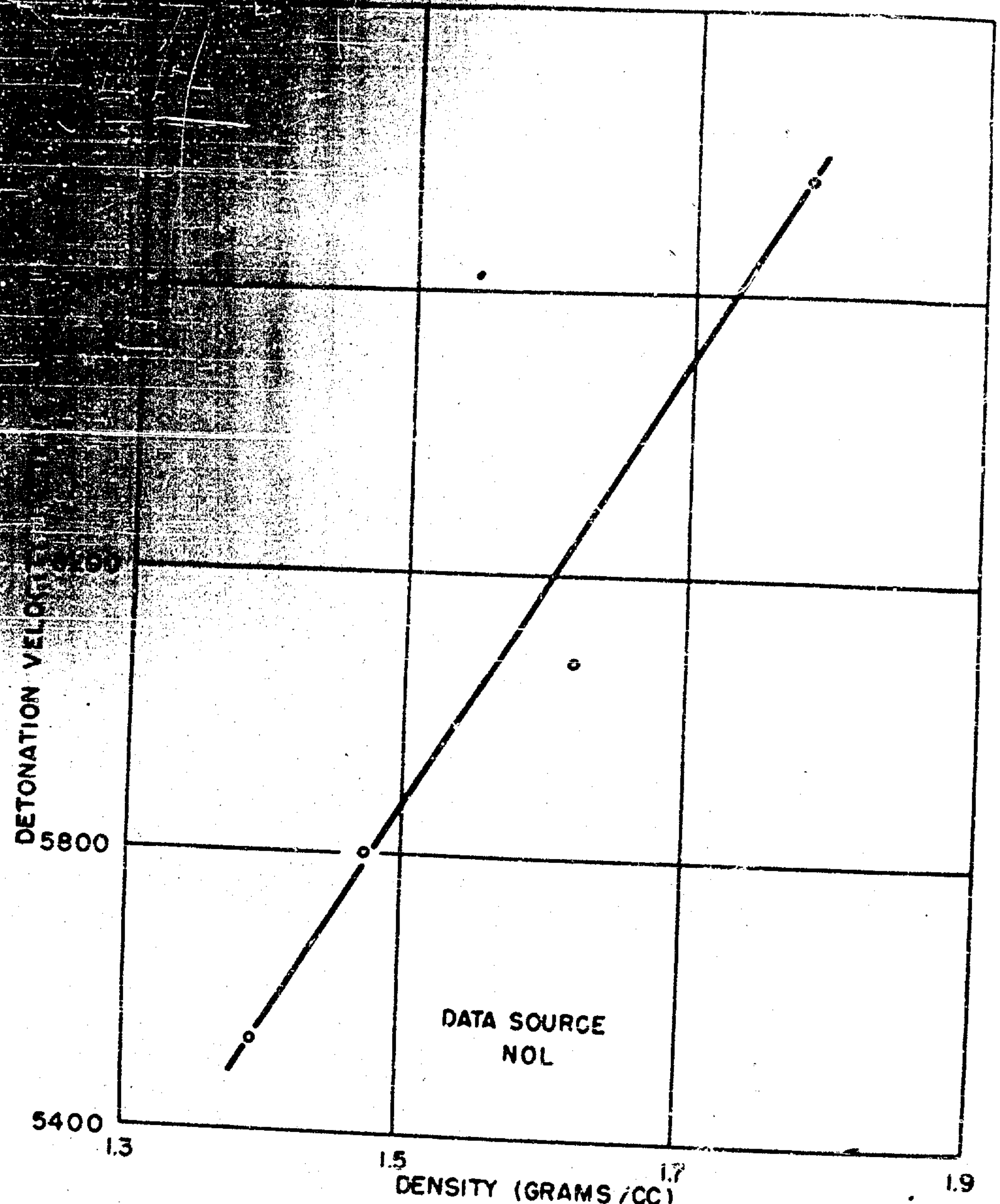

Figure 2–4. Diazodinitrophenol, Density vs. Detonation Velocity.

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Priming Mixtures

Pure primary explosives are not suitable for use as initiators in many applications. In order to modify their characteristics, various materials are added and thoroughly mixed with primary explosives to form priming mixtures.

The following four methods are commonly employed to impart particular characteristics to priming mixtures.

Increasing sensitivity. Since most explosives have a low oxygen balance, the addition of oxidizing agents such as chlorates or nitrates will usually increase the sensitivity. In the case of priming mixtures initiated by the action of stab and percussion firing pins, an abrasive such as ground glass or carborundum may be added to increase the sensitivity. The addition of a small amount (5 percent or so) of a sensitive primary explosive such as tetracene will often increase the sensitivity of a priming mixture.

Increasing output. The output of priming mixtures is usually augmented by the addition of fuels such as antimony trisulfide and lead sulfocyanate. The former fuel also serves as an abrasive. Since most explosives have low oxygen balances, the addition of fuel to priming mixtures is usually accompanied by a suitable amount of an oxidizing agent. In some cases, the addition of an oxidizing agent alone will increase both sensitivity and output. High explosives such as RDX and TNT are also used to increase the output, although these materials probably do not detonate when used in this way.

Loading binders. For purposes of loading by the buttering process, priming mixtures may be wetted by a solution containing a binder. After the solvent evaporates, the mixture is held in place by the binder. Such binders are often explosives such as nitrocellulose or nitrostarch, used with suitable solvents such as butyl acetate.

Improving electrical conductivity. It is sometimes desirable to make priming mixtures conductive, either for purposes of electrical initiation by currents passed through the mixture or to decrease the sensitivity to static electric discharges. Powdered graphite and colloidal metal powders have been used for this purpose.

The compositions of current U. S. Army and Navy priming mixtures are presented in table 2–3, together with an indication of the type of device in which they are used. Comparative data on the sensitivity and output characteristics of these mixtures, when available, are presented in sections of the book dealing with the respective devices.

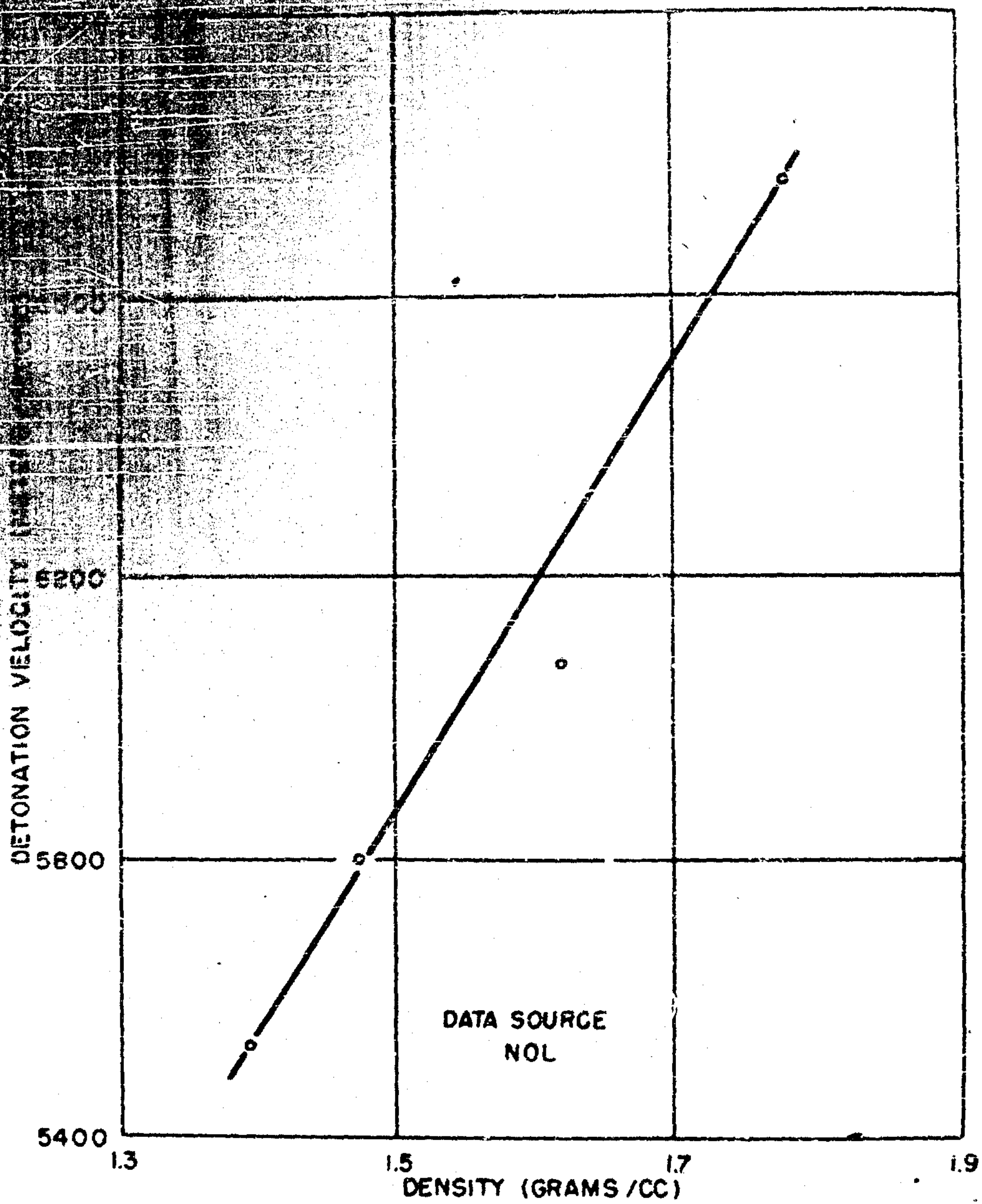

Figure 2–4. Diazodinitrophenol, Density vs. Detonation Velocity.

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17. FA 675 (Army) [6] used in percussion primers			82	18												
18. FA 675A (Army) [7] used in percussion primers			82	18												
19. FA 716 (Army) [6] used in percussion primers			77	18							5					

[1] Mixture milled with a solution of 2.4 percent nitrostarch in butyl acetate.

[2] Mixed with Gum Solutions: Tragacanth, 120 gms/3668 ml. H_2O Acacia, 220 gms/3668 ml. H_2O glue, 1¼ Test, Copper's Std, 20 gms/332 ml. H_2O. Thymol, USP, 2 gm/20 ml. 95 percent Ethyl Alcohol.

[3] Mixed with Gum Solution: Sodium Alginate, 60 gms. Glue, 1¼ Test, Copper's Std., 40 gms. Distilled H_2O, 6,000 ml. Thymol, 10 gms/100 ml. 95 percent Ethyl Alcohol.

[4] Moisten a 6 lb. batch with 330 ml. of: 33.3 percent Gum Tragacanth, 60 gms. 61.1 percent Acacia (Gum Arabic), 110 gms. 5.6 percent Gelatin Glue, 10 gms. H_2O, 3,000 ml.

[5] The dried normal lead styphnate is moistened with a solution containing about 0.5 percent of Hercules R. S. ½ sec. cellulose nitrate in butyl acetate.

[6] Gum solution described under (3) added in amount to give 0.8 percent solids.

[7] Gum, solution described under (3), added in amount to give 0.93 percent solids.

[illegible] have the characteristic of low sensitivity to he[illegible] [illegible] are generally more brisant and powerful than th[illegible] [illegible]. High explosives function under the influence of [illegible] of a primary explosive or of another high explosive. They [illegible] in their sensitivity to shock as well as in their brisance. [illegible] primary explosives, most high explosives in an unconfined [illegible] will burn without exploding when ignited with a flame. The [illegible] data on physical properties, explosive characteristics, and [illegible] characteristics of a number of the more important high [illegible] are presented in tables 2-4 and 2-5. The information [illegible] is discussed more fully in the following paragraphs.

[illegible] 2-4 lists a number of the more common high explosives by [illegible] widely accepted names. Chemical and physical data are included.

The explosives listed in table 2-5 are arranged in the decreasing order of their impact sensitivities. The values for booster sensitivity, brisance, and rate of detonation are dependent on loading densities. The densities entered in this table may be uniformly obtained, under good loading conditions, for the forms stated; but the usual densities obtained in production loading may fall as much as 0.05 unit below the cited values. The values reported are typical of those currently being obtained. Additional data on loading densities will be found on pages 2-24 and 2-25.

Oxygen balance. The significance of the oxygen balance data is explained on page 2-3.

Booster sensitivity is expressed as the length in inches of a cylinder of Acrawax B 1⅝ inches in diameter that will fail to transmit detonation 50 percent of the time from a tetryl booster 1⅝ inches in diameter and 2 inches high to a cylinder of a particular explosive 1⅝ inches in diameter and 5 inches long. The test arrangement is shown on page 7-10. Table 2-5 gives the booster sensitivity of 13 commonly used high explosives.

Brisance, by the plate-denting test, is expressed as a ratio. It is the ratio of the average depth of dent in cold-rolled steel produced by the explosive at the indicated density to the average depth of dent produced by cast TNT at a density of 1.60. The test sample, cast or pressed in a cylinder 1⅝ inches in diameter and 5 inches long, uncased, is fired on a lightly greased, square, cold-rolled steel plate 5 inches on a side and 1¾ inches thick. The charge is initiated with a No. 8 blasting cap and two 30-gram tetryl boosters.

TABLE 2-4.—*Physical Properties of High Explosives*

[Reference numbers at heads of columns indicate sources of data]

Explosive	Formula or composition	Mol. weight	Color	(7) Melting point (degrees C)	(7) Crystal density	(7) Oxygen balance (percent)
PETN-Pentaerythritol Tetranitrate	$C(CH_2ONO_2)_4$	316.15	White	139	1.77	−10.1
RDX-(Cyclonite) Cyclotrimethylene Trinitramine.	$(CH_2)_3(NNO_2)_3$	222.13	do	202	1.82	−21.6
Pentolite 50/50	PETN/TNT; 50/50		Buff	76 [1]		
PTX-2	RDX/PETN/TNT; 43.2/28.0/28.8		do	75 [1]		
Tetryl-2,4,6-Trinitrophenyl methylnitramine	$C_6H_2(NO_2)_3N(CH_3)NO_2$	287.08	Yellow	130	1.73	−47.3
EDNA-(Haleite) Ethylene dinitramine	$C_2H_4(NHNO_2)_2$	146.07	White	178	1.71	−32.0
Torpex-2 [2]	Comp.B/TNT/Al; 70/12/18		Gray	79 [1]		
Composition B	RDX/TNT/Wax; 60/40/1		Yellow to Brown	79 [1]		
Composition A-3	RDX/Wax; 91/9		Buff to White			
Ednatol 55/45	EDNA/TNT; 55/45		Yellow to Brown	79 [1]		
Picric Acid-2,4,6-trinitrophenol	$C_6H_2(NO_2)_3OH$	229.11	Yellow	122	1.76	−45.3
HBX	Composition B/TNT/Al/D-2 [3]; 70/12/18/5		Gray	79.0 [1]		
Tritonal 80/20	TNT/Al; 80/20		do	80.5		
TNT-2,4,6-trinitrotolene	$C_6H_2(NO_2)_3CH_3$	227.13	Buff	80.5	1.65	−74.0
Picratol 52/48	Expl.D/TNT; 52/48		Yellow	80.0		
Explosive D-Ammonium Picrate	$C_6H_2(NO_2)_3ONH_4$	246.14	do	256	1.72	−52.0

[1] Eutectic Temperatures.
[2] Torpex-2 plus 0.5 percent anhydrous CaCl is called Torpex-3.
[3] D-2 desensitizer has the composition wax/nitrocellulose/lecithin; 84/14/2.

TABLE 2-5.—*Explosive Characteristics of High Explosives*

[Reference numbers at heads of columns indicate sources of data. Values in parentheses are arbitrarily assigned standard values to which other values in column are referenced]

Explosive	Normal form	(10) Loading density	(11) Booster sensitivity (inches)	(10) Relative brisance (plate test)	(10) Rate of detonation (m/sec)	(12) Relative power (BM)	Relative impact sensitivity	(3) Thermal properties (K Cal/Mole 25° C) $-H_c$	$-H_f$	$-H_e$
PETN	Pressed	1.60		136	7,920	145	(10)	619.7	+125.9	441.3
RDX	do	1.60		131	8,235	150	18	506.8	−18.4	271.0
Pentolite 50/50	Cast	1.65	1.93	121	7,450	126	19			
Do	Pressed	1.61	2.36							
PTX-2	Cast	1.70	1.57	141	7,900	138	30			
Do	Pressed	1.61	2.32							
Tetryl	do	1.55	2.01	112	7,375	126	24	839.1	+7.3	249.9
EDNA	do	1.50	2.09	113	7,550	137	25	370.9	+25.1	145.3
Torpex-2	Cast	1.80	1.67	120	7,530	134	38			
Comp. B	do	1.69	1.39	132	7,700	134	41			
Comp. A-3	Pressed	1.60	1.70	121	8,200	135	43			
Ednatol 55/45	Cast	1.62	1.28	112	7,330	119	47			
Picric Acid	do	1.60		108	7,080	112	52	613.4	+53.6	162.6
HBX	do	1.73	1.25	106	7,400	133	68			
Tritonal	do	1.75	.56	93	6,770	124	71			
TNT	do	1.60	.82	(100)	6,850	(100)	(100)	816.7	+15.1	143.3
Do	Pressed	1.55	1.68							
Picratol 52/48	Cast	1.63	1.00	100	6,915	100	130			
Explosive D	Pressed	1.54	1.37	87	7,050	99	150	677.1	94.5	121.7

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Detonation velocities (meters/second) are given for each explosive at the density and form stated in the table. All charges were between 1.6 and 2.0 inches in diameter (the majority being 1.6 inches), and the rates of detonation represent maximum velocities for the densities given. The velocity is a direct function of density and changes about 370 meters/second for each change of 0.10 gram/cc in density. This relationship may be used for estimating detonation velocities at other densities.

Power, as determined by the Ballistic Mortar, is expressed in terms of percent of the value for TNT. This test was designed to evaluate approximately the total energy from the explosive. The use of the mortar is described in reference (12).

Impact sensitivity measured by the ERL type 12 machine refers to the 50 percent explosion height obtained at the Naval Ordnance Laboratory on the Drop-Weight Impact Machine, adjusted to give PETN the index 10 and TNT the index 100. This machine is described in reference (2).

Thermal properties. The values reported for heat of formation (H_f) and heat of explosion (H_e) were derived from the measured values for heat of combustion (H_c). The methods used to obtain these values are the same as those discussed on page 2–4.

Section 2. Common Delay and Igniter Powders

For convenience of discussion, delay and igniter powders are divided into three groups: gasless powders, black powder, and other materials used in short delays.

Gasless Powders

The distinguishing characteristics of gasless delays and igniters are that the combustion products are normally solids and that a negligible quantity of gas is formed during burning. They are generally employed in the form of a mixture of dry powders, usually of subsieve particle size. The mixture is pressed into a delay cavity at loading pressures in the neighborhood of 35,000 psi. Binders are not commonly employed because they tend to form gases during burning. The pellet formed in the delay cavity by the pressed powder has sufficient strength to withstand ordinary handling during transportation as well as low acceleration forces. However, when the magnitude of the acceleration forces approaches those resulting from setback in medium caliber projectiles, the pressed powder usually must be supported mechanically at the ends of the delay cavity.

Gasless igniters are used to transfer ignition from an initiator to the delay mixture or from the delay mixture to an explosive charge. The igniters are easily ignited and their heat of combustion is usually greater than 350 cal/gm. (refs. (43) and (44)).

F33B. This is a red powder manufactured by the Catalyst Research Corporation. It is composed of 41 percent zirconium (Zr), which serves as the fuel, 49 percent iron oxide (Fe_2O_3), which serves as the oxidizing agent, and 10 percent superfloss (SiO_2), which is an inert ingredient whose principal function appears to be to decrease the rate of burning. There are no other known manufacturing specifications. F33B has a drop weight sensitivity comparable to that of lead azide, and it has been fired by body static electricity. F33B can be initiated by standard percussion primers, as well as by black powder, and glows upon initiation, forming a solid slag.

Under some circumstances F33B may react explosively upon initiation, and this tendency appears to increase as the quantity of F33B is increased. It is usually advisable to restrict any possible movement of the igniter after initiation to insure its remaining in contact with the delay or explosive charge which it is intended to ignite. The storage qualities (44) in brass and stainless steel containers are good, and the heat developed upon combustion is in the neighborhood of 500 cal/gm. (44).

Z–3 Igniter. This is a green powder composed of 25 percent zirconium and 75 percent barium chromate. It is manufactured by the Catalyst Research Corporation; there are no known manufacturing specifications. The heat developed upon combustion is in the neighborhood of 430 cal/gm. (ref. (44)). Because of the satisfactory performance of F33B, the testing of Z–3 Igniter has been restricted. However, its initiation, combustion, and storage qualities appear to be similar to those of F33B.

6-6-8 Igniter. This pyrotechnic igniter containing lead dioxide, cupric oxide, and silicon in the ratio of 6-6-8 parts by weight has been used experimentally as a gasless delay igniter. Tests indicate that its impact, static sensitivity, and storage qualities (ref. (44)) are similar to those of F33B. Its heat output is about 400 cal/gm. (ref. (44)). However, it has been found that this igniter is difficult to ignite at low ambient temperatures, and, therefore, its use is not widespread.

Silicon-red lead igniter. A silicon-red lead mixture (ref. (45)) has been used by Picatinny Arsenal to ignite one of their delay mixtures. Complete performance data on this mixture are not available.

Gasless Delays

Gasless delay mixtures usually cannot be ignited directly from a primer and require a small quantity of igniter to aid in their initiation. The mixtures are practically insensitive to initiation by shock or static electricity, and their heats of combustion usually are less than 350 cal/gm.

Zirconium-nickel delay mixtures. A new delay composition of zirconium-nickel alloy, potassium perchlorate and barium chromate has been developed by Picatinny Arsenal (ref. (37)). The surface of the alloy is treated with a dichromate solution (ref. (46)) to prevent subsequent deterioration. The storage qualities of this mixture appear to be good, and it appears to be compatible with F33B igniter. No other information on its performance is available.

Manganese-barium chromate-lead chromate mixture. The development of a delay mixture composed of manganese, barium chromate, and lead chromate is described in references 36, 48, and 49. By varying the proportions of the ingredients, the burning time may be varied from about 3 to 12 seconds per inch of delay column. Tests have shown that this mixture will function at −65° F. (ref. (36)), and preliminary data have indicated that it may perform satisfactorily at −100° F. Loading pressures in the neighborhood of 30,000 psi have proved sufficient to enable this mixture to withstand impacts as heavy as those to which an A. P. projectile is subjected on being fired

[illegible] These deceleration forces have been estimat[ed] [illegible] 000 and 250,000 G's. The surveillance characte[ristics] [illegible] mixture appear to be satisfactory when the mangane[se] [illegible] improve its oxidation resistance and when the mixtur[e] [illegible] bodies. No information is available on the storag[e] [illegible] the mixture when loaded in other types of delay bodies.

[illegible] delay mixture. This is a greenish powder developed and [illegible] by the Catalyst Research Corporation. It is composed of [illegible], potassium perchlorate, nickel, and barium chromate in the approximate proportions 5/7.5/17/70.5. There are no known manufacturing specifications. The surveillance characteristics of early mixtures were known to be poor; this fact was traced to the nickel powder used. The manufacturer appears to have overcome this difficulty (refs. (36) and (50)) by deactivating the surface of the powdered nickel. Data on low temperature performance are conflicting (refs. (36) and (50)). One report indicates good performance at −65° F., while the other lists failures at +32° F. Additional data from current tests indicate that this difficulty may be dependent upon the particular batch of powder being tested.

Barium peroxide-selenium mixture. A gasless delay furnished by the Hercules Powder Company (ref. (51)) has been used in electric fuze primers Mk 115, Mk 116, and Mk 117. The mixture is composed of approximately 80 percent barium peroxide and 20 percent selenium. The storage qualities and the dispersions appear to be poor (ref. (52)), and recent tests indicate that reliability and low temperature performance are not satisfactory.

Manganese-barium chromate-sulfur mixture. A delay mixture consisting of manganese, barium chromate, and sulfur (refs. (13), (53), and (54)) was developed at Picatinny Arsenal. This has been discarded because of limited storage life at 65° C.

Antimony-potassium permanganate mixture. A delay mixture consisting of antimony and potassium permanganate was used extensively in Germany during World War II (ref. (55)). Very little information is available, but it is known that the moisture content of the mixture is very critical and that sufficient moisture may be adsorbed from a normally loaded detonator to cause failures.

Silicon delay mixtures. Several delay mixtures (refs. (45), (56), (57), (58) and (59)) developed at Picatinny Arsenal consist of silicon, red lead, and/or lead chromate, and a binder. Difficulties were experienced in obtaining reproducible burning times and continuity of burning after the delay elements were subjected to severe impact forces.

Cobalt delay mixture. Some data (ref. (36)) have been obtained

on the performance of a mixture of surface treated cobalt (ref. (47)), lead chromate, and potassium perchlorate. The storage qualities of this mixture appeared to be good, but no other information on its performance is available.

Black powder. Black powder is a mechanical mixture of potassium or sodium nitrate, charcoal, and sulfur, in proportions of 70–75, 14–16 and 10–14, respectively. Potassium nitrate is usually used for military purposes, while sodium nitrate is used in commercial blasting powder and in saluting charges (ref. (16)). Specifications for various grades of black powder for military uses are given in reference 17. Table 2–6, reproduced from this reference, shows the granulations of the various grades.

On burning, black powder produces relatively large amounts of gases, together with a considerable amount of incandescent solid particles (white smoke). The analysis of the combustion products from one sample of black powder is presented in table 2–7, which was taken from reference (18). The heat of combustion of black powder has been reported (ref. (18)) as 718 cal/gm. (1292 BTU/lb), while its flame temperature is recorded as 3880° F (2138° C). The ignition temperature of black powder varies widely with the test conditions. Values reported in reference (19) for potassium nitrate base powder vary from 164 to 290° C, depending on the rate of heating. Under similar conditions, the ignition temperature of the sodium nitrate base powder appears to be about 100° C higher than that of the potassium nitrate powder.

The pressure which black powder will build up in a confined space can be calculated from the "impetus," which may be defined as the pressure times the volume of the gases produced by a given weight of powder, or:

$$\frac{\text{Volume (cu. ft.)} \times \text{Pressure (lb./sq. ft.)}}{\text{Wt. Powder (lbs.)}} = \text{Impetus}$$

Several determinations of the impetus of 3FG black powder were made at the Naval Ordnance Laboratory using a 500 cc (0.0176 cu. ft.) bomb equipped with an Aberdeen type strain gage. The results are summarized here.

Charge weight (grams)	Peak pressure (psi)	Impetus (ft lb/lb)
30	25,000	95,885
30	25,000	95,885
30	26,750	102,596
30	25,000	95,885
30	25,000	95,885
15	12,750	97,802

TABLE 2-6.—*Granulation of Black Powder (ref. (17))*

Sieve Size	4	6	8	12	12	14	16	16	20	20	25	30	40	40	45	50	100	100	140	200
R-Retained on T-Through	R	R	T	R	T	R	R	T	R	T	T	T	R	T	R	T	R	T	T	T
Micron Size	4760	3360	2380	1680	1680	1410	1190	1190	840	840	710	590	420	420	350	297	149	149	105	[illegible]
Grade A-1, percent (max.)	3.0		5.0																	
Grade A-2, percent (max.)	3.0				5.0															
Cannon, percent (max.)		3.0			5.0															
Grade A-3, percent (max.)				3.0				5.0												
Grade A-3a, percent (max.)				3.0						5.0										
Musket, percent (max.)						3.0					5.0									
FFG, percent (max.)							3.0					5.0								
Grade A-4, percent (max.)							3.0							5.0						
Shell, percent (max.)							3.0													
FFFG, percent (max.)									3.0											
Grade A-5, percent (max.)													3.0							
Fuse, percent (max.)													3.0							
FFFFG, percent (max.)																				
Grade A-6, percent (max.)																				
Grade A-7, percent (max.)																				
Meal, percent (min.)																				

TABLE 2-7. *Combustion of Black Powder (ref. (18))*

Powder Analysis (percent by weight)	Potassium nitrate	74.430
	Potassium sulfate	.133
	Sulfur	10.093
	Charcoal	14.286
	Water	1.058
Product Analysis (percent by weight)	Gases	42.98
	Solids	55.91
	Water	1.11
Analysis of Gases (percent by volume)	Carbon dioxide	49.29
	Carbon monoxide	12.47
	Nitrogen	32.91
	Hydrogen sulfide	2.65
	Methane	.43
	Hydrogen	2.19
Analysis of Solid Products (percent by weight)	Potassium carbonate	61.03
	Potassium sulfate	15.10
	Potassium sulfide	14.45
	Potassium thiocyanide	.22
	Potassium nitrate	.27
	Ammonium carbonate	.08
	Sulfur	8.74
	Carbon	.08

Black powder has a tendency to absorb moisture, a property which may affect its burning characteristics. Moisture may be absorbed in such large quantities that the powder will not burn. The effect of smaller quantities of moisture upon the ignitability is shown in figure 2-5 (ref. (19)). In this investigation, the black powder was exposed to a flame for a definite time interval. Ten trials were made at each time interval, and the number of ignitions obtained was designated as the probability of ignition. This probability was plotted against exposure time, and the time required for an ignition probability of 0.5 was used in calculating the ignitability of the sample:

$$\text{Ignitability} = \frac{100}{\text{Time of exposure to flame (sec)}}$$

Further discussion of the effect of moist air on black powder will be found on page 2-30.

The burning rate of black powder may be slowed considerably by incorporating other ingredients in the mixture (ref (20)). The duPont Company manufactures a slow-burning black powder which bears the designation D-55. It has no Army-Navy specification.

The compatability of black powder with various metals is shown in table 2-14.

Black powder fuses. Black powder is used in the construction of a number of fuses employed to obtain delays in a number of applications, including fuzes. The most widely used types are quickmatch, firecracker fuse, and safety blasting fuse.

Quickmatch. Quickmatch is made by impregnating a cotton wick with mealed (finely powdered) or unmealed black powder. Gum arabic or dextrine is used as a binder. This fuse is highly sensitive to moisture and must be kept dry for proper functioning. Quickmatch

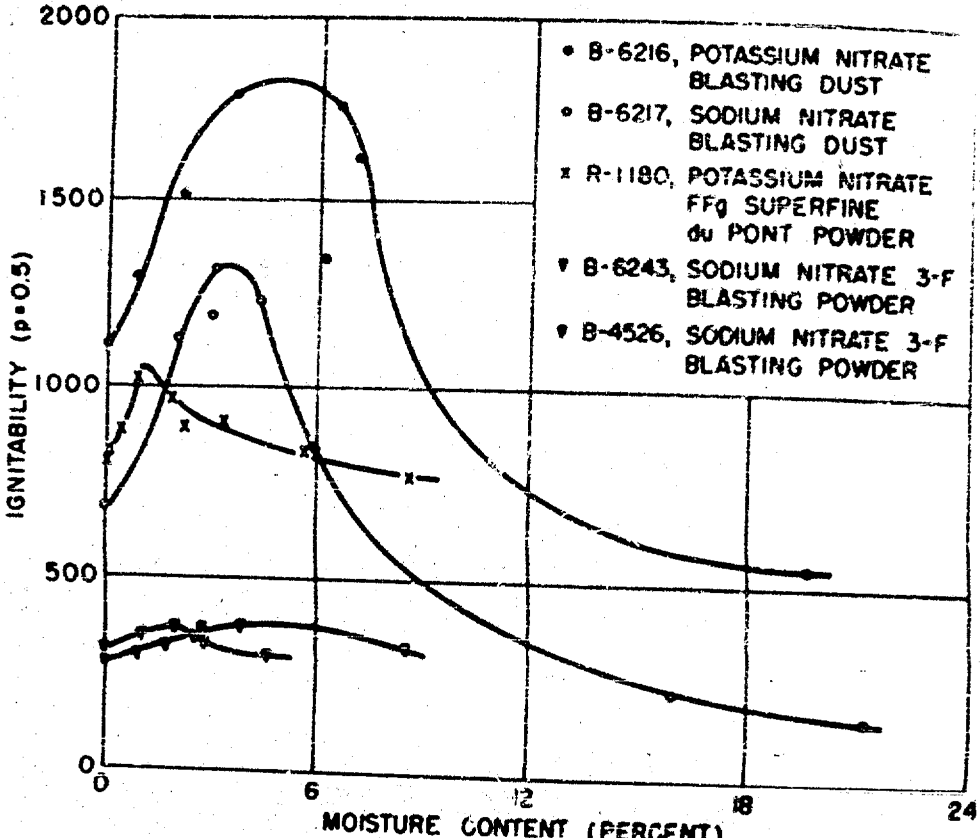

Figure 2–5. Effect of Moisture on Ignitability of Black Powder.

burns almost instantaneously when confined. The unconfined burning characteristics of various classes of quickmatch as presented in reference (21) are reproduced in table 2–8.

Firecracker fuse. This is a slower burning, more rugged fuse consisting of a core of black powder and cotton threads surrounded by an outer layer of cotton threads impregnated with lacquer. Its unconfined burning time varies from 15 to 30 seconds per foot. The rate of burning is increased by confinement. It is moisture resistant and will function satisfactorily after immersion for periods up to 20

TABLE 2–8.—*Burning Specifications for Quickmatch (ref. (21))*

Type and Class	Description	Maximum (unconfined) burning time (sec.) for 12 inch length
Type I, Class A	4 Strand, Mealed Powder	8
Type I, Class B	4 Strand, Unmealed Powder	12
Type II, Class A	6 Strand, Mealed Powder	10
Type II, Class B	6 Strand, Unmealed Powder	17
Type III, Class A	Mealed Powder [1]	8
Type III, Class B	Unmealed Powder [1]	12

[1] 4 Strand intertwined with annealed copper wire 0.0142 inch in diameter.

minutes. It is normally furnished in diameters of 1/16 to 1/8 inch. Reference (40) presents Government specifications on 30-second firecracker fuse.

Safety blasting fuse. This is commonly known as Ensign Bickford Fuse. It is made by braiding and spinning cotton threads impregnated with a tar-like substance over a black powder core and then coating with wax. It can be obtained with burning times varying from 25 to 120 seconds per foot. It is fairly moistureproof. It is obtainable only in a diameter of 0.2 inch. Reference (41) presents Government specifications on 120-second blasting fuse.

Other Materials Used in Short Delays

Normal lead styphnate. This has been used in an experimental 4-millisecond delay initiated by an electric primer. In this application, 10.4 mg of normal lead styphnate is dead pressed at 80,000 psi in a delay cavity 1/16 inch in diameter and 0.075 inch long. The burning rates of the freshly prepared delays are consistent and range from 3 to 5 milliseconds. However, after several months exposure at 95 percent relative humidity and 140° F, the burning rates become erratic and may fall below 1 millisecond. The surveillance deterioration is being investigated.

Normal lead 2,4-dinitroresorcinate. This has been used in an experimental 5-millisecond delay initiated by an electric primer. Nine milligrams of lead dinitroresorcinate is pressed at 60,000 to 80,000 psi into a cavity, 1/16 inch in diameter and 0.064 inch long. Preliminary data indicate that such delays have satisfactory stability in surveillance under conditions of high temperature and high relative humidity.

Section 3.—Use and Handling Characteristics of Explosive Train Materials

The performance characteristics of explosive train materials are considered in sections 1 and 2. This section presents data on some of the secondary characteristics, which are helpful in connection with the use and handling of these materials.

Use Characteristics

Data on loading pressure versus loading density, temperature of explosion, electrostatic sensitivity, storage stability, compatability, and solubility are presented in the following paragraphs.

Loading density. The available information on the effect of pressure on the loading density of a number of explosives is summarized in

TABLE 2-9.—*Loading Density of Explosives (gm/cc)*

[Data given in this table are principally from references (22) and (23). Other sources are Naval Ordnance Laboratory experiments, marked (a), and a communication from L. R. Littleton, Department of the Army, ORDTM, marked (b)]

Explosive	(Pressure psi/1000) 3	5	10	12	15	20	Cast	Crystal density
Mercury Fulminate	3.00	3.20	3.60	3.67	3.82	3.90	....	4.4
Lead Azide	(a) 2.46 2.62	(a) 2.69 2.71	(a) 2.98 2.96	(a) 3.05	(a) 3.16 3.07	(a) 3.28	....	4.[illegible] to 4.72
Tetracene	1.05 1.12	(a) 1.22	(a) 1.33	(a) 1.37	(a) 1.41	(a) 1.48	....	....
Lead Styphnate (Normal)	(a) 2.12	(a) 2.24	(a) 2.43	(a) 2.47	(a) 2.57	(a) 2.63	....	3.1
Cyclonite (RDX)	1.455	1.52	1.60	1.63	1.65	1.675	....	1.82
PETN	....	(a) 1.48	(a) 1.61					1.76
Tetryl	1.40	1.47	1.57	1.60	1.63	1.67	....	1.73
EDNA (Haleite)	....	(b) 1.386	(b) 1.456	....	(b) 1.503	(b) 1.56	....	1.71
TNT	1.34	1.40	1.47	1.49	1.515	1.55	1.56–1.59	1.65
Composition-B	....	....	(a) 1.59	....	....	....	1.67	....
Pentolite (50–50)	....	....	(a) 1.39	....	....	....	1.65	....
Composition A-3	1.47	....	(a) 1.61	1.65	....	....	....	....
Picric Acid	1.4	1.5	1.57	1.59	1.61	1.64	1.71	1.76
HBX	....	....	....	....	....	....	1.69	....
Tritonal 80/20	....	....	....	....	....	....	1.65–1.72	....
Picratol 52/48	....	....	....	....	....	....	1.62	....
Explosive D	1.33	1.41	1.47	1.49	1.61	1.64	1.71	1.72

table 2–9. In case the explosive may be cast, the casting density has been included if available. The crystal densities of the pure explosives have also been included to serve as an indication of the ultimate loading density.

A nomograph which may be used for estimating the loading density of several commonly used explosives is presented in figure 2–6 (ref. (42)). Table 2–10 presents data on the loading density of black powder. Discrepancies which may be noted between values given in table 2–9 and those obtained from figure 2–6 may be attributed to variations in loading conditions and materials. Loading density is a function of particle size distribution and other factors that depend on the sample and on the conditions of loading. Accordingly, loading

TABLE 2–10.—*Effect of Loading Pressure on the Density of Grade A Black Powder (ref. (24))*

[Loaded into pellet 0.05 inch in diameter × 0.25 inch in height]

Pressure (psi)	Density of pressed pellet (gm/cc)
0	1.1 (est. from ref. (30))
3,000	1.32
5,000	1.55
10,000	1.64
25,000	1.74
35,000	1.80
50,000	1.83
75,000	1.88
100,000	1.885
Void Free	1.89 (ref. (30))

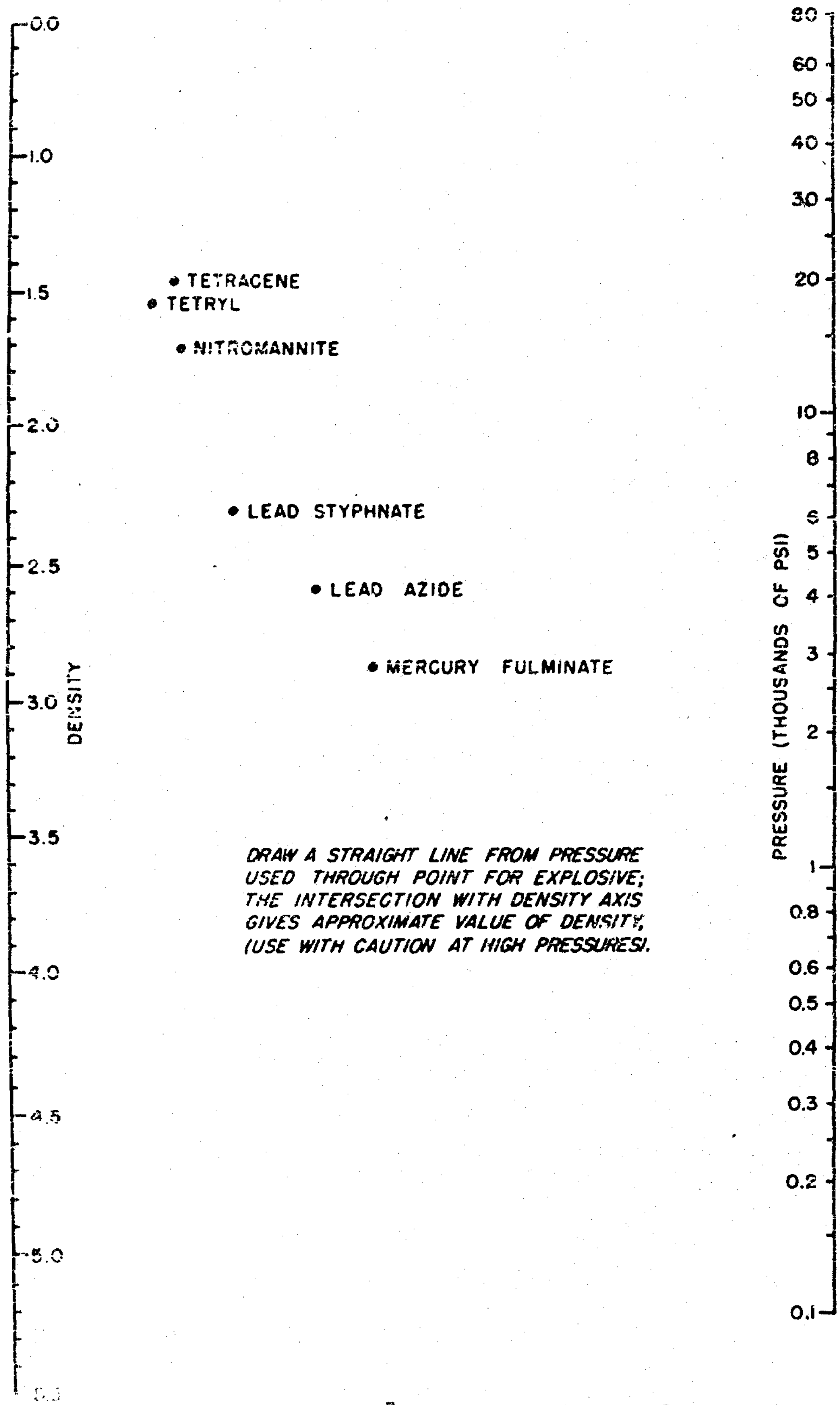

Figure 2-6. Nomograph for Estimating Loading Density.

density values should be considered as an approximation of what would be expected with average materials and with good loading practices.

Temperature of explosion. The temperature of explosion is not a well-defined property since the values obtained vary widely with the test conditions. If, however, the conditions are closely controlled, reproducible values may be obtained, and it is found that the time required for the explosion to occur is an inverse function of the temperature. If the log of the time required for an explosion is plotted against the reciprocal of the absolute temperature, a straight line is obtained. The slope of this line may be used to calculate activation energy (ref. (25)). The temperature of explosion is thus seen to be a variable which for a given set of test conditions can be defined by the temperature at which an explosion will occur in a given time and the slope of the curve of the log of the time versus the reciprocal of the absolute temperature.

Since there is a statistical distribution of energy among the molecules in a substance, it may be assumed that at any temperature above absolute zero some of the molecules of a metastable substance will have sufficient energy to decompose. If the heat produced by such random decompositions is not dissipated, it will raise the temperature of the substance; in turn, the rate of decomposition will increase. This self-accelerating process, termed the "growth of explosion" (ref. (1)), eventually will lead to a complete and probably violent decomposition if it is unchecked. Under normal storage conditions, the heat generated by random molecular decompositions is dissipated to the surroundings and the substance reaches equilibrium at a temperature slightly higher than that of its surroundings.

The relationship between the size and shape of the explosive charge and the temperature necessary for an explosion to occur is discussed in reference (1). It defines the former as "critical explosion size" and the latter as "critical explosion temperature." Accordingly, an infinitely large piece of explosive will always explode after a finite time, depending on the initial temperature. If the size is finite and the charge is contained in a nonconducting envelope, the self- accelerating reaction results in an explosion. However, if the sample is finite and heat is able to escape through its surface, there may or may not be an explosion.

Any metastable substance has been considered capable of spontaneously exploding if stored in amounts which are supercritical. It is estimated that mercury fulminate in the form of a slab 3.1 meter thick would explode at the temperature of a Washington, D. C. summer (92° F). Cylinders and spheres of the same material with diam-

eters of 4.8 meters and 6.0 meters, respectively, would also explode spontaneously (ref. (1)).

In spite of the fact that the explosion temperature is not a property that can be evaluated with precision, it is nevertheless useful to have some qualitative indication of this property. The data presented in table 2-11 are relative estimates of this characteristic. Data showing the variation of explosion time with temperature for many of these explosives will be found in references (23) and (25).

TABLE 2-11.—*Explosion Temperature (degrees C)*

[Reference numbers at heads of columns and opposite items indicate sources of data. Letters refer to footnotes]

Explosive	(29)	(23)	(25)[1]	(25)[2]	(35)[3]
Mercury Fulminate	177–180	190–263	175	240	195
Lead Azide	-----	335–396	315	340	292
Lead Styphnate	-----	267–282	280	320	260
DDNP	170	195	165	195	-----
Tetracene	-----	160	-----	-----	-----
Nitromannite	-----	175	-----	232 (7)	-----
PETN	170–175	211–272	215	255	232
RDX	203–208	235–405	360+	-----	316
Pentolite (50/50)	174–178	190–290	-----	-----	238
PTX-2	203 (33)	-----	-----	-----	-----
Tetryl	164–165	234–340	265	300	326
EDNA	165–173	170–265	150	205	222
Composition B	260–526	280	-----	-----	436
Composition A-3	-----	250	-----	-----	373
Ednatol (55/45)	159–165	168–435	-----	-----	-----
Picric Acid	300–304	320	265	360	418
HBX	207 (33)	250	-----	-----	440
Tritonal (80/20)	190–300	465–610	-----	-----	-----
TNT	288–292	465–570	360+	-----	456
Picratol (52/48)	246 (33)	255–456	-----	-----	-----
Explosive D	288–291	295–405	360+	-----	418
Black Powder	-----	356–510	320	360+	-----

[1] Lowest explosion temperature observed.
[2] Temperature for explosion in one second.
[3] 50 percent probability of explosion, aluminum bar method.

Sensitivity to electrostatic discharge. The amount of energy required for the initiation of explosives by a source of energy, such as an electric spark, varies widely with conditions. As a consequence, the energy required for initiation by electrostatic discharge is not a basic or well-defined property of an explosive. However, the possibility of chance initiation by electric sparks represents a hazard in the handling of certain explosives, and an indication of the comparative electrostatic sensitivity of various explosives is of some practical importance.

Table 2-12 summarizes electrostatic sensitivity data from two sources. The apparatus used to obtain the Bureau of Mines data is described in reference (4), and that used to obtain the Naval Ordnance Laboratory data is described in reference (38). It appears that particle size has a very great influence on sensitivity, the smaller particle sizes having the greater sensitivity.

TABLE 2-12.—*Electrostatic Sensitivity of Primary Explosives*

(5000 volts, varying capacity)

Explosive	Sample description	Particle size	Where tested	Maximum energy for non-ignition (ergs)
Mercury Fulminate		−100	Bureau of Mines [1]	210,000
Lead Azide		Subsieve	NOL (?)	707,500
	Dextrinated	−100	Bureau of Mines [1]	70,000
	Dextrinated	Subsieve	NOL [2]	100,000
Silver Azide	From Western Cartridge	−100 +200	NOL [2]	75,000
	From Hercules	Subsieve	NOL [2]	7,000
Normal Lead Styphnate		−100	Bureau of Mines [1]	9,000
		Subsieve	NOL [2]	13,250
		Milled	NOL [2]	70
Basic Lead Styphnate		Subsieve	NOL [2]	7,000
Tetracene		−100	Bureau of Mines [1]	120,000
	From Naval Powder Factory	Subsieve	NOL [2]	382,500
	From Winchester	Subsieve	NOL [2]	350,000
Nitromannite		25 Mesh	NOL [2]	35,000,000
DDNP		−100	NOL [2]	562,500
		−100	Bureau of Mines [1]	120,000
	Recrystallized Sample	−200	NOL [2]	2,562,500
		−100	NOL [2]	2,625,000

[1] Reference (1).
[2] Determined on 15 mg of loose explosive in a 0.218 inch ID plastic cup with a grounded steel bottom, using a 0.03 inch spark gap. Apparatus described in reference (38).

Measurements on the capacity of the human body to build up static energy (ref. (5)) showed a value of 0.0003 microfarad to be not uncommon. If a person is charged to 5000 volts, which is a reasonable figure, the energy would be of the order of 37,500 ergs. Thus, it appears that the highly sensitive explosives may easily be ignited by a spark from a person, and this conclusion has been experimentally confirmed.

Stability of explosive train materials. Table 2-13 gives stability and surveillance data on a number of explosives. The vacuum stability test is a measure of the rate at which gaseous decomposition products are liberated from a 5-gram sample of the explosive heated in vacuo, usually at 120° C for 48 hours. The thermal stability test measures the time required for a 0.5-gram sample of the explosive, when heated to 135° C, to liberate a sufficient quantity of oxides of nitrogen to discolor a strip of methyl violet paper. Times are re-

TABLE 2-13.—*Stability of Explosives*

Explosive	Vacuum Stability (10)		Thermal Stability at 135° C Time (min.)	Surveillance Characteristics
	Temp. (degrees C)	cc gas/5grams/48 hours		
Mercury Fulminate				Rapidly deteriorates in high temperature storage, dry or wet. (23) (26) Life of 10 to 15 days at 80° C. (27).
Lead Azide	100 (23) 120 (23)	1.0 (40 hrs) 0.07 (40 hrs)		Surveillance at 80° C for 960 days showed no loss of power. (27)
Lead Styphnate	100 (23) 120 (23)	0.4 (40 hrs) 0.4 (40 hrs)		2 months storage at 80° C showed no effect on power or sensitivity. (23)
DDNP	100 (23)	7.6 (40 hrs)		No loss in power after 5 months storage, dry or wet. Darkens in direct sunlight.
Tetracene				No significant change after 2 months storage at 75° C. (7).
Nitromannite				Decomposes in a few hours at 75° C, stable at room temperature. (7)
PETN	120	3.0	135	Surveillance at 65° C for 4 months, no change in stability. Storage for 450 hours at 100° C caused no decomposition. (7)
RDX	120	1.5 (24 hrs)	NA	Surveillance, no deterioration in 11-13 months at 65° or 85° C. (7)
Pentolite 50/50	100	2.0	45	Surveillance, storage at 65° C for 11 months, no decrease in stability. (7)
PTX-2	100	4.0	45	
EDNA	120	3.0	NA	Surveillance, no decrease in stability, slight lowering of M. P. on storage for 4 months at 65° C. (7)
Tetryl	120	1.0	110	No decomposition in 185 eight-hour days at 95° C. (7)
Torpex 2	120	2.0	NA	
Comp. B	120	0.5	NA	Surveillance, no deterioration in 14 months at 65° C. (7)
Comp. A-3	120	0.5	NA	Does not exude at 65° C when waxes melting sharply at above 75° C are used.
Ednatol 55/45	100	0.5	NA	Satisfactory storage characteristics. (28)
Picric Acid	120	0.5	NA	Damaged by moisture. (28) Contact with heavy metals forms explosive salts. (7)
HBX	120	2.0	NA	Satisfactory storage characteristics. (28)
Tritonal 80/20	120	0.2	NA	Satisfactory storage characteristics. (28)
TNT	150	0.8 (24 hrs.)	NA	Satisfactory storage characteristics. (28)
Picratol 52/48	120	0.2	NA	
Explosive D	120	0.2	NA	Satisfactory storage characteristics. (28) No significant change in power or sensitivity after 3.5 years at 50° C and 2 years at magazine temperature. (23)
[illegible]				Stable if humidity is not excessive. See page 2-30.

corded in minutes. The test was discontinued if no reaction was observed at the end of 5 hours; this result is indicated by the symbol NA (no action). A description of the vacuum and thermal stability test methods is given in reference (29).

The surveillance characteristics of black powder are of particular interest because of the wide use of this material. It can be said that black powder has remarkably good surveillance characteristics provided it is kept reasonably dry. Potassium nitrate is soluble in water and will be leached out if the powder comes in contact with liquid water. Likewise, if the relative humidity becomes high enough, water will condense on the powder and a leaching action will occur. It was found (ref. (30)) that at 86° F no leaching occurred at relative humidities of 89 percent or below, but that leaching did occur at 95 percent relative humidities. Theoretical considerations indicate that leaching will occur if the relative humidity is such as to correspond to a partial pressure of water vapor which is equal to or higher than the vapor pressure of a saturated solution of potassium nitrate. Using literature values for the vapor pressure of water and of saturated potassium nitrate solution, the following data have been calculated.

Temperature (degrees C)	Relative Humidity (Predicted) Above Which Black Powder Will Be Leached (percent)
0	96
20	94
40	88.5
60	81.5
80	74

Compatibility of explosive train materials. The available information on the compatibility between explosives and explosives and between explosives and structural materials is summarized in table 2–14. The explosives are listed in the approximate order of decreasing sensitivity as they appear in tables 2–1 and 2–4 with black powder added to the list. The data in table 2–14 are limited to moist conditions. Some of the source references contain compatibility data obtained under dry conditions, but these have not been included because in most cases there was no assurance that moisture was completely excluded.

Solubility of explosives. The available data on the solubilities of a number of pure explosives in water, alcohol, acetone, and benzene are summarized in table 2–15.

TABLE 2-11.—*Compatibility of Explosive M*

[Code: A = No reaction; B = Slight reaction; C = Reacts readily; D = Reacts to form sensitive mate

Material in Contact with Explosive	Mercury fulminate	Lead azide	Lead styphnate	Diazodinitrophenol	PETN	R
Magnesium	C(23)				B(23)	
Aluminum	C(23)	A(27)	A		A(23)	A
Zinc	B(23)	C(27)				A
Iron	A(23)					A
Steel	A(23)	C(27)			B(23)	A
Tin		A(27)				A
Cadmium		C(27)				
Copper	B(23)	D(77)	A	B	B(23)	A
Nickel		C(27)				A
Lead						A
Steel coated with acid proof black paint					B(23)	
Cadmium plated steel					B(23)	
Copper plated steel					B(23)	B
Nickel plated steel					B(23)	A
Zinc plated steel					B(23)	A
Tin plated steel						A
Parkerized steel						
Steel with baked oil finish						
Magnesium-aluminum alloy					B(23)	
Monel metal		C(27)				
Duraluminum		A(27)				
Brass	B(23)	D(7)			B(23)	A
Bronze	B(23)					A
Shellac coated brass						
Tin plated brass						
NRC coated brass						
Stainless steel (19-6)		A(27)	A		A(23)	A
Stainless steel (18 chrome)		A(27)				
Heavy metals						
Lead azide			A	C(7)		
Black powder			A			

[1] Reported to react slowly to form sensitive salts, probably under slightly acidic conditions.

xplosive Materials in the Presence of Moisture

sitive materials. Reference numbers in parentheses refer to sources of data. (1) refers to footnote]

EXPLOSIVES

ETN	RDX	Pentolite-50/50	PTX-2	Tetryl	EDNA	Composition B	Composition A-3	Ednatol-55/45	Picric acid	TNT	Picratol 52/48	Explosive D	Black powder
B(23) A(23) ...... B(23)	...... A(31) A(31) A(31) A(31) A(31)	B(23) A(23) ...... B(23)	...... A(23) ...... A(23)	A(31) B(31) B(31) C(31) A(31)	B(23) ...... C(23)	C(23) A(23) ...... B(23)	B(23) B(23) ...... B(23)	C(23) B(23) ...... C(23)	....	A(31) B(31) A(31) A(31) A(21)	....	A(31) A(31) A(31) C(31) A(31)	...... B(31) C(31) C(31) C(31)
B(23)	A(31) A(31) A(31)	B(23)	....	A(31) A(31) A(31)	C(23)	B(23)	B(23)	C(23)	....	B(31) A(31) B(31)	....	[1] A(31) A(31) [1] A(21)	C(31) C(21) C(31)
B(23) B(23) B(23) B(23) B(23)	...... B(31) A(21) A(31) A(31)	A(23) B(23) B(23) B(23) B(23)	....	...... A(31) A(31) A(31) B(31)	C(23) C(23) C(23) C(23) C(23)	B(23) B(23) B(23) B(23) B(23)	B(23) B(23) B(23) B(23) B(23)	C(23) C(23) C(23) C(23) C(23)	....	B(31) B(31) A(31) A(31) A(31)	....	A(21) B(31) C(31) B(31) B(21)	A(21) A(31) C(31) C(31) A(31) C(31) B(31) A(31)
...... B(23)	....	...... B(23)	....	....	...... C(23)	...... C(23)	....	....	....	....	....	....	....
B(23)	A(31) A(21)	B(23)	....	B(31) A(31)	C(23)	B(23)	B(23)	C(23)	....	A(31) B(31)	B(29)	A(31) B(31)	C(31) C(31) A(31) B(31) A(31)
A(23)	A(31)	A(23)	....	A(31)	A(23)	A(23)	A(23)	A(23)	...... D(7)	A(31)	....	A(31)	A([illegible]) ....

TABLE 2-15.—*Solubility of Explosives in Some Common Solvents (Grams/100 Grams of Solvent)*

[Reference numbers in parentheses indicate sources of data. Letter (a) refers to footnote]

Explosive	Water		Ethyl Alcohol		Acetone		Benzene	
	Temp (° C)	Solubility	Temp (° C)	Solubility	Temp (° C)	Solubility	Temp (° C)	Solubility
Mercury Fulminate (32)	12	0.7						
	49	1.76						
Lead Azide	20	0.05(22)						
Lead Styphnate								
DDNP (23)			50	2.43			50	0.23
Tetracene								
Nitromannite (23)		Insol.	Hot	Soluble				
			Cold	Slightly soluble.				
PETN (22)	0	do	0	0.070	0	14.37	0	0.150
	80	do	20	.195	20	24.95	20	0.450
			40	.415	40	30.55	40	1.160
			60	1.205	60	42.68	60	3.350
							80	7.900
RDX (23)	30	0.005	0	.040	0	4.4	20	.05
	50	.025	20	.105	20	7.3	40	.09
	70	.076	40	.240	40	11.5	60	.20
	90	.19	60	.579	60	18.0	80	.41
	100	.28	78	1.195				
Tetryl (23)	0	.0050	0	0.320 (a)	20	75	20	7.8
	20	.0075	10	.425 (a)	30	95	30	10.0
	40	.0110	20	.563 (a)	40	116	40	12.5
	60	.0350	30	.76 (a)	50	138	50	16.9
	80	.0810	50	1.72 (a)				
	100	.184	75	5.33 (a)				
EDNA (23)	20	.25	20	1.00				
	40	.75	40	2.46				
	60	2.13	60	5.19				
	80	6.38	78	10.4				
	100	20						
Picric Acid (23)	0	.85	0	4.5	20	125	0	2
	20	1.17	20	6.9	30	137	20	9.6
	40	1.88	40	12.0	40	164	40	27.5
	60	2.98			50	208	60	59
	80	4.55						
	100	7.4						
TNT (23)	0	.0100	0	.62	0	57	0	13
	20	.0130	20	1.25	20	109	20	67
	40	.0285	40	2.85	40	228	40	180
	60	.0675	60	8.4	60	600	60	487
			70	15.0				
plosive D (23)	20	1.1		.515				
	100	75	10	.690				
			30	1.050				
			50	1.800				
			80	3.620				

(a) 95 percent alcohol.

Handling Characteristics

Information which should be useful in the storage and handling of explosive train materials is presented in table 2–16. This table includes data on types of storage, precautions in storage and handling, and solutions useful for destroying the explosive without undue hazard.

TABLE 2-16.—*Handling Characteristics of Explosive Train Materials*

[Reference numbers in parentheses indicate sources of data]

Explosive	Storage	Precaution	Destroying solution
Mercury Fulminate	Wet	Sensitive to flame and sparks (22).	Saturated sodium thiosulfate (16).
Lead Azide	do	Sensitive to flame and sparks. Forms sensitive copper azide (22).	Ammonium acetate (1[illegible]).
Lead Styphnate	do	Sensitive to flame and to static electricity (see page 2-[illegible]).	Sodium carbonate.
DDNP	do	Sensitive to flame	Cold sodium hydroxide.
Tetracene	do	do	
Nitromannite	do		
PETN	do		Hydrolyzed slowly by alkalies (22).
RDX	do	Sensitive mixtures with iron and copper oxides, poison when taken orally (22).	Hot sodium hydroxide (22).
Pentolite 50/50	Dry		
PTX-2	do		
EDNA	do	Forms compounds with metals	
Tetryl	do	Dust explosion hazard (22); contact with skin may cause dermatitis (7).	Boiling sodium carbonate (22).
Torpex-2	do		
Composition B	do		
Composition A-3	do		
Ednatol	do		
Picric acid	do	Forms sensitive lead and copper salts.	
HBX	do		
Tritonal 80/20	do		
TNT	do	Slightly toxic (22) (16); reacts with alkalies and ammonia to form sensitive compounds (22)	
Picratol	do		
Explosive D	Dry-wooden containers.	When wet reacts [illegible] with lead and copper to form sensitive salts.	
Black powder	Dry	Particularly sensitive to flame and sparks.	

Section 4: References

Parenthetical numbers preceded by the letter "S" are Naval Ordnance Laboratory file numbers.

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(2) OSRD Report No. 5744, **Physical Testing of Explosives,** December 1945. (S-7987).

(3) Clark, L. V., **Diazodinitrophenol, A Detonating Explosive,** Ind. Eng. Chem., Vol. 25, No. 6, pp. 663-669, June 1933.

(4) U. S. Bureau of Mines Report R. I. 3852, **Sensitivity of Explosives to Initiation by Electrostatic Discharges.** January 1946 (S-21702).

(5) U. S. Bureau of Mines Tech. Note No. 23, **Ignitability of Explosives by Static Electricity,** November 1943. (S-5784).

(6) U. S. Bureau of Mines Bulletin No. 347, **Physical Testing of Explosives.** 1931.

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(8) Little, A. D., **Study of Pure Explosive Compounds.** C–57625, Office of Chief of Ordnance Contract No. W–19–020–Ord–6436, Cambridge 42, Mass. 1947. (S–12043).

(9) OSRD Report No. 5306, **Heat of Combustion of Explosive Substances.** July 1945. (S–8339).

(10) OSRD Report No. 5746, **Physical Testing of Explosives.** November 1945. (S–8099).

(11) NOLM 10336, **The Sensitivity of High Explosives to Pure Shocks.** July 14, 1949.

(12) OSRD Report No. 804, **Methods of Physical Testing.** August 1942. (S–2804).

(13) Picatinny Arsenal Technical Report, Serial No. 1432, **Manufacture of Barium Chromate Delay Powder in a Semi-Plant Scale.** February 28, 1946. (S–12921).

(14) B. I. O. 8664, Detonator Factory, D. A. G. Troisdorf. (S–13285).

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(18) Davis, T. L., **The Chemistry of Powder and Explosives.** John Wiley & Sons, New York, 1943.

(19) Bureau of Mines Report R. I. 3782, **Studies of the Effect of Humidity on the Sensitivity and Dispersion of Black Powder,** November 1943. (S–21703).

(20) **A Manual for Explosives Laboratories, Vol. II Explosive Compounds and Allied Substances,** page B–5, by G. D. Clift and Dr. B. T. Federoff. Lefax Society, Inc., Philadelphia, 1943.

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Chapter 3

CHARACTERISTICS OF PRIMERS

The primer usually occupies the initial position in the explosive train and, accordingly, is generally the most sensitive element in the train. The priming mixture may be initiated by either mechanical or electrical energy. Fuze primers are classified as stab, percussion, or electric, depending on the nature of the initiation. Available information on the characteristics of each of these types is summarized in the following sections.

Section 1: Stab Primers

General Performance Characteristics

Stab primers are small, initiating elements that are highly sensitive to the action of a stab-type firing pin. The explosive charge is designed to evolve a quantity of gas at high temperature for the purpose of: (1) Accomplishing mechanical work; (2) initiating a burning action in pyrotechnic and explosive charges; or (3) initiating the explosive charge in a flash detonator.

Applications. Stab primers are used by the Navy to perform mechanical work. For example, Primer Mk 102 expands the inner cup of a fuze of the Mk 28 type and drives a firing pin into the secondary primer. Primer Mk 100 in one application drives a pin into a glass vial.

Stab primers are used by the Army to ignite a black-powder charge. Army Primer M45 includes an ignition charge within the stab primer assembly in addition to the priming charge. Although American practice has been to use percussion type primers for the initiation of sealed delay elements, several foreign fuzes which have been examined have a stab primer, together with its firing pin, enclosed within such an element. In one such fuze, initiation results from setback forces; in another, initiation results from impact forces.

Advantages. Stab primers may be made to possess a higher degree of sensitivity than percussion primers. Therefore, where little energy for initiating an explosive train is available, stab primers may be used advantageously.

Disadvantages. Stab primers are initiated by driving a firing pin into the sensitive end of the primer case. The resulting hole allows combustion products to escape from this end of the primer. In many applications, this design is undesirable from the standpoint of pressure control and the possibility of fouling moving parts.

Construction

Stab primers are small, explosive items consisting of an explosive charge contained in a cylindrical cup. The sensitive end of Navy stab primers is closed by a very thin metal cover disk crimped into place. The closure of the opposite end may be of the same type (in this case the metal is turned over and the disk placed prior to loading) or the cup may have a closed end. Stab primers currently in use by the Army and Navy vary in size from 0.16-inch diameter by 0.100-inch length (Navy Primer Mk 102) to 0.241-inch diameter by 0.340-inch length (Army Primer M45).

Primary Explosive. The usual explosive charge of stab primers is a mixture of an explosive ingredient combined with a fuel and oxidizer to increase the heat and quantity of gas formed during the explosion. Sensitivity to mechanical energy stands high in the list of required characteristics of these mixtures. The lead azide priming mixture used in Navy Primer Mk 100 includes an abrasive which serves as a sensitizing agent. Data on the more important priming mixtures now being used by the Army and Navy are presented in table 2–3.

The Navy has experienced considerable difficulty with Primer Mk 102 Mod 0 (Pom Pom No. 74 priming mixture) in that deterioration takes place in a relatively short time in the highly humid, ammoniacal atmosphere of Explosive D loaded projectiles. The life characteristics of NOL No. 130 mixture used in Primer Mk 102 Mod 1 are much superior to those of Pom Pom No. 74 under these conditions.

TABLE 3–1.—*Compositions of Some of the More Sensitive Stab Priming Mixtures*

Mixture	Composition	Percent
Pom Pom No. 74	Mercury Fulminate	32
	Antimony Sulfide	23
	Potassium Chlorate	45
OS 891 Mixture	Potassium Chlorate	45
	Antimony Sulfide	22
	Lead Sulfocyanate	33
FA 100	Potassium Chlorate	53
	Antimony Sulfide	17
	Lead Sulfocyanate	25
	Lead Azide	5
FA 70	Potassium Chlorate	53
	Antimony Sulfide	17
	Lead Sulfocyanate	25
	TNT	5
Lead Azide Priming Mixture	Potassium Chlorate	33⅓
	Antimony Sulfide	33⅓
	Lead Azide	28⅓
	Carborundum	5
NOL No. 130	Basic Lead Styphnate	40
	Barium Nitrate	20
	Lead Azide	20
	Tetracene	5
	Antimony Sulfide	15

In an effort to find a priming mixture suitable for a particular application, a direct comparison was made between the sensitivities and outputs of a number of the more sensitive stab priming mixtures. In this study, the priming mixtures were loaded (at 15,000 psi) into Mk 102 Mod 0 primer cups (50 primers for each mixture), closed with the standard closing procedure for Primer Mk 102, and then subjected to sensitivity and output tests on Detonator Test Set Mk 136 (see page 9–4), using a two-ounce ball. The compositions of the mixtures are given in table 3–1.

The results of sensitivity and output tests of primer cups loaded with the various mixtures are given in table 3–2.

TABLE 3–2.—*Sensitivities and Outputs of Some of the More Sensitive Stab Priming Mixtures*

Mixture	Input (Sensitivity)		Output (Power)	
	Ht. of 50% functioning (inches)	Standard deviation (inches)	Average lead disk indentation (inches)	Standard deviation of lead disk indentations (inches)
Pom Pom No. 74	0.85	0.21	0.0670	0.0045
OS 891	1.02	0.24	.0179	.0044
FA 70	1.09	0.22	.0199	.0051
PA 100	1.19	0.39	.0384	.0051
Lead Azide Priming Mixture	2.52	1.29	.0757	.0199
NOL No. 130	0.93	0.25	.0577	.0033

Construction metals. Metals for components vary with the primer charge. Navy practice is to load mixtures containing fulminate into copper or copper base metals. Mixtures containing lead azide are loaded into cups formed from aluminum or aluminum base alloys.

In the two stab-type primers used by the Army, the priming mixture is encased in a gilding metal (copper base) cup. The inside surfaces of the cups are painted with dyed (for identification purposes) shellac to prevent contact between the azide of the priming mixture and the copper of the primer cup (ref. 17). It is a policy of the Navy not to load lead azide into copper base metals although no written statement or directive to that effect is known to exist.

Figure 3–1 illustrates three of the more common stab primers in use by the Army and Navy.

Effects of Construction Details on Input Characteristics

Firing pin shape. Because of the similar initiating energy input available for functioning stab primers and stab detonators, the details of firing pin construction are the same. The most widely used con-

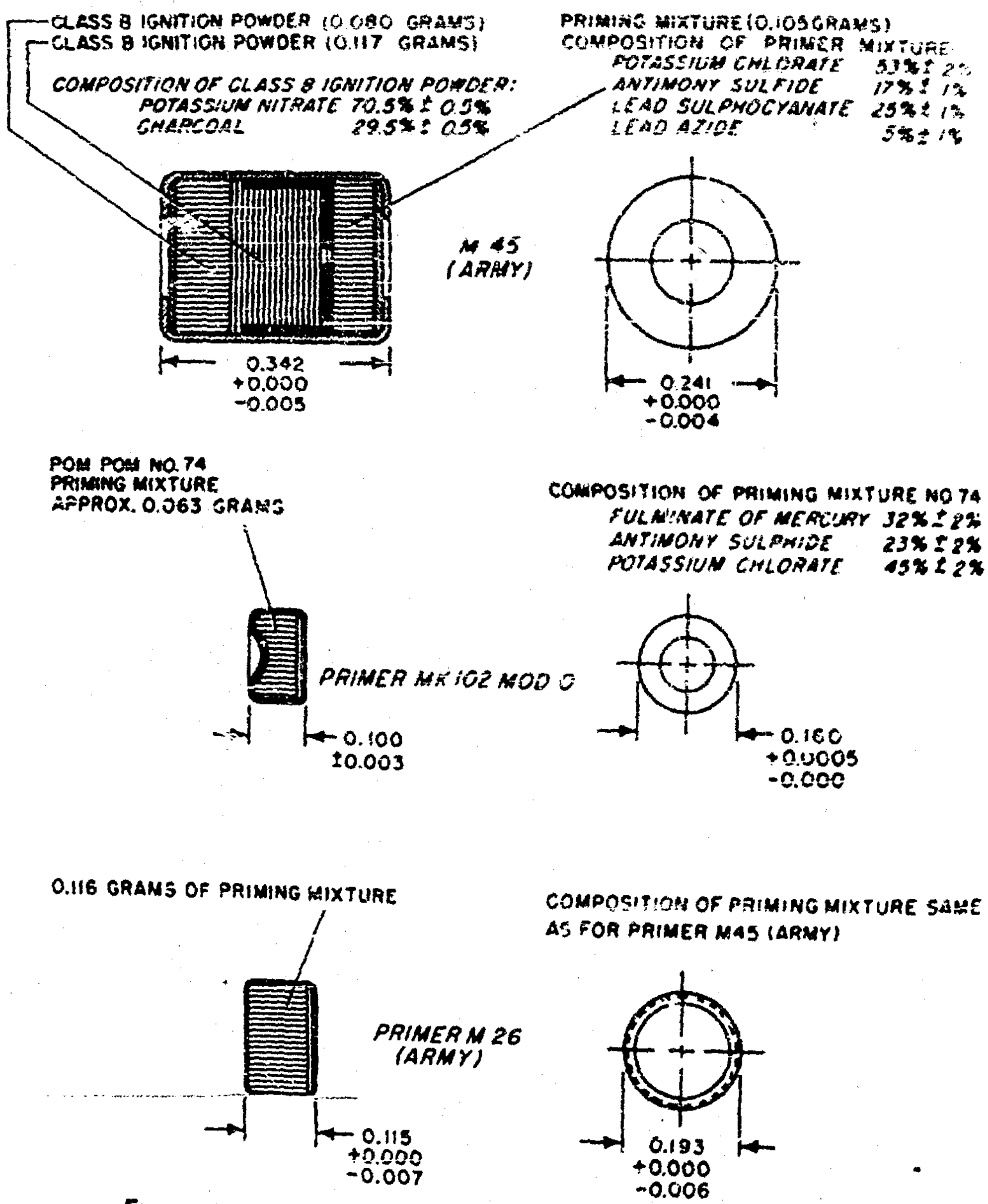


Figure 3-1. Stab Primers in Use by the Army and Navy.

tour of the firing end of firing pins is that of a truncated cone. This contour is convenient from a manufacturing viewpoint and gives a satisfactory performance for initiating stab primers and detonators.

The angle of the conical section of the firing pin has been found to show increased apparent primer sensitivity as the included angle is decreased (refs. (2) and (3)). Strength limitations determine the minimum angle to be used. Above 26 degrees, the required energy input increases rapidly; accordingly, the upper limit of firing pin angle should not exceed 26 degrees by any greater amount than strength considerations demand.

Limited tests on Italian firing pins (ref. (5)) with firing points of pyramidal contour, as shown in figure 3–2, indicate that these would initiate detonators on 56 percent of the energy input required by the conical design used by the Navy. Pyramidal designs appear to offer considerable promise for low-energy applications in spite of the fact that they probably are more difficult to manufacture.

The required energy input varies only slightly with changes up to about 0.015 inch in the diameter of the flat on the end of the firing pin; above 0.015 inch, the required energy input increases at a much higher rate (refs. (3) and (4)).

A very important consideration with respect to uniformity and high sensitivity is the corner, or arris, between the flat and the taper of the firing pin point (ref. (1)). A sharp corner gives the best functioning. The maximum radius permitted should be governed to some extent by available manufacturing facilities and firing pin flat, but should be held to 0.002 inch or less where practical.

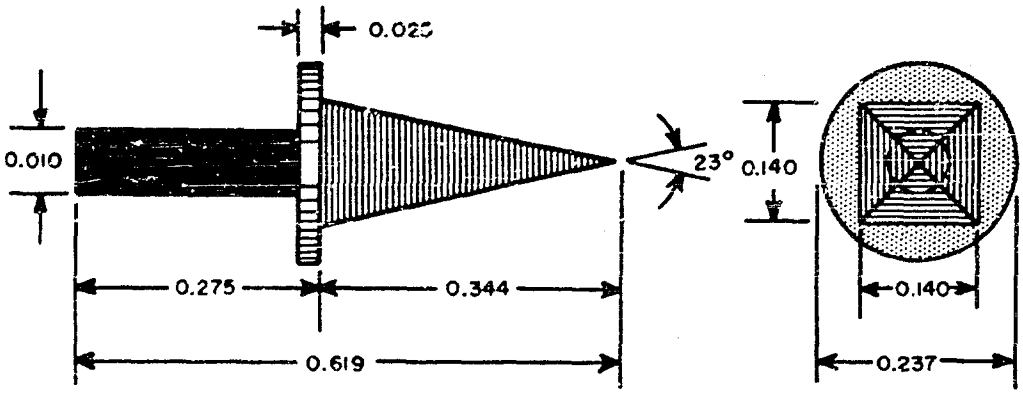


Figure 3–2. Firing Pin from Italian Ammunition.

As a result of studies of firing pin contour, the Naval Ordnance Laboratory chose the following typical dimensions as representing a highly satisfactory pin contour.

firing pin flat: 0.010 inch ± 0.003 inch
angle of cone: 28 degrees ± 2 degrees
radius of corner: sharp preferred, 0.002 inch maximum

These dimensions have been standardized by the Navy for test firing pins for stab primers and detonators. Newly designed fuze firing pins approach these dimensions as nearly as possible.

Firing pin material. Both steel and aluminum have been used by the Navy for the manufacture of fuze firing pins. Reference (1) reports tests in which sensitivity was measured by identical procedures except that in one case aluminum firing pins were used and in the other

TABLE 3-3.—*Mk 102 Type Primer, Disk Thickness vs. Sensitivity (Test S. 136, 2-Ounce Ball)*

Disk thickness (inches)	Height of 50 percent functioning (inches)
0.001	1.82
.002	2.38
.003	2.39
.005	4.53
.010	6.01

case steel firing pins were used. Items tested with steel firing pins showed slightly greater sensitivity, but the difference was not of sufficient magnitude to preclude the use of a variety of metals for the manufacture of firing pins.

Disk thickness vs. input requirements. Data available on disk thickness vs. input requirements are somewhat meager. A test was conducted at the Naval Ordnance Laboratory in which lead azide priming mixture was loaded into aluminum cups of Mk 102 primer cup design and covered with disks of various thicknesses. Fifty samples were prepared with each thickness of disk. The results of a sensitivity test on these primers are presented in table 3-3.

The results shown graphically in figure 3-3 fall on a straight line. In addition to variations in disk thickness, several points are included on the graph which show the sensitivity of primers into which several disks have been assembled. These latter data were included for the

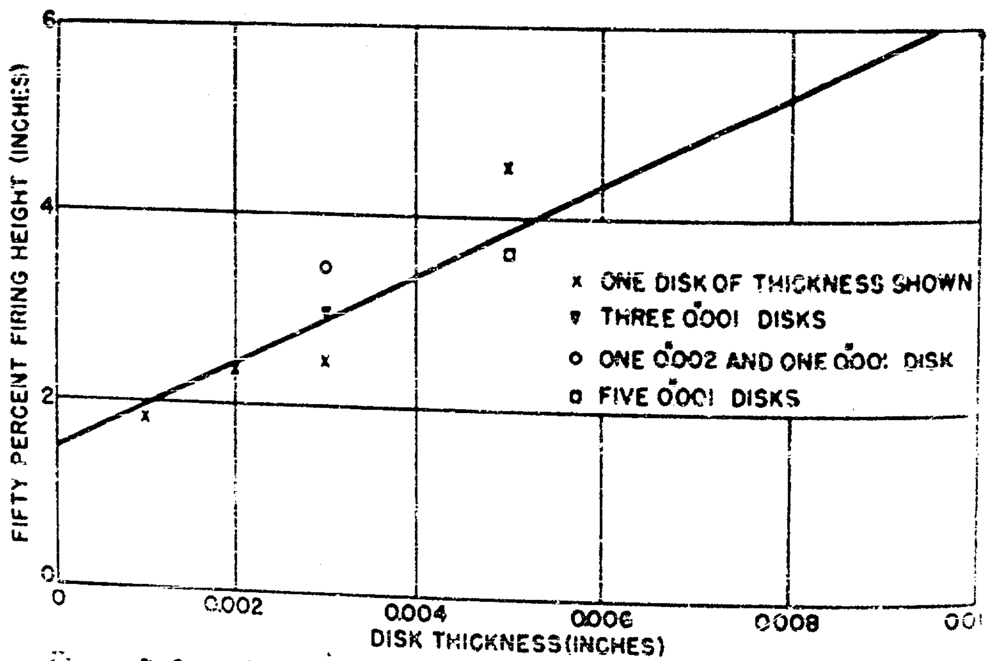


Figure 3-3. *Mk 102 Type Primer, Disk Thickness vs. Sensitivity.*

reason that several disks are occasionally assembled into stab primers and detonators through error.

Effect of firing pin velocity on input requirements. Work conducted at the Naval Ordnance Laboratory showed a definite relationship existing between energy input requirements and firing pin velocity for the initiation of Primer Mk 102 (formerly designated "Sensitive Primer Mk 19") (ref. (5)). There appear to be two possible conditions under which initiation will not occur: (1) where the total transfer of energy is large but the rate of transfer is low; and (2) where the rate of transfer is high but total energy is low. In other words, there is a minimum energy requirement as well as a minimum velocity requirement for firing stab primers. Between these two extreme conditions, there seems to be a hyperbolic relationship between impact velocity and total energy requirements, as illustrated by figure 3-4. Additional data of this type may be found in reference (16).

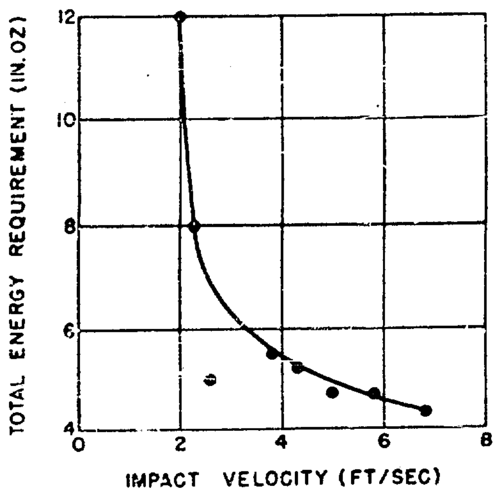


Figure 3–4. Primer Mk 102 Sensitivity Tests with Standard Navy Test Firing Pin. Plot of Impact Velocity vs. Total Energy Required for 100 Percent Firing.

Effect of Loading Techniques

Effect of loading pressure on input requirements.

It has been demonstrated that the sensitivity of some priming mixtures is virtually unaffected by loading pressure, while others show a marked increase in sensitivity with increasing pressure. In tests on Mk 102 Mod 0 type primers loaded with the mercury fulminate priming mixture Pom Pom No. 74, no change in sensitivity was noted when varying the loading pressure from 10,000 to 30,000 psi (ref. (6)).

In similar tests on the experimental NOL No. 103 priming mixture (lead azide/tetracene/barium nitrate/antimony sulfide—30/5/40/25),

TABLE 3-4.—*Effect of Loading Pressure on Sensitivity of NOL Priming Mixture No. 130 Loaded into Mk 102 Mod 1 Primer Cups*

Wt of NOL No. 130 priming mixture (mg)	Drop Test (2-ounce Ball)		
	Loading pressure (psi)	50 percent height (inches)	Standard deviation (inches)
62	15,000	1.31	0.34
65	25,000	.91	.29
68	40,000	.77	.24
70	60,000	.66	.18
70	80,000	.57	.15

no change in sensitivity was noted over the same range of loading pressures.

The NOL No. 130 priming mixture, however, shows a marked increase in sensitivity with increased loading pressure. Data in this connection as applied to detonators are presented in chapter 4 under the discussion of Input Characteristics (page 4–10). Corresponding data obtained on the NOL No. 130 priming mixture loaded into Mk 102 Mod 1 primer cups are presented in table 3–4.

These data show that both sensitivity and uniformity are improved by high loading pressures. In an effort to determine the minimum obtainable firing energy for stab primers, Mk 102 Mod 1 cups were loaded with NOL No. 130 priming mixture at a pressure of 80,000 psi. These primers were then tested with a one-ounce ball with the pyramidal firing pin discussed on page 3–5. The mean drop height obtained was 0.65 inch with a standard deviation of 0.23 inch. This value of 0.65 inch-ounces compares favorably with the mechanical energy required to fire the most sensitive known electric generator-primer systems.

During the study of the effect of firing pin velocity and loading pressure on input requirements, the primers tested were supported on lead disks. Measurements of the indentations produced in the lead disks by the explosions of the primers yielded data on primer output under these conditions. A discussion of the output data follows.

Output Characteristics

Effect of loading pressure on output. Tests on NOL No. 130 and Experimental Priming Mixture No. 103 loaded into Mk 102 type cups have indicated that the loading pressure has no significant effect on output. These data are presented in table 3–5.

The lead disk reading, which is used as a measure of the strength of the primer, shows no significant difference for the various loading pressures within the range of pressures used.

TABLE 3-5.—*Effect of Loading Pressure on Output of Priming Mixtures Used in Stab Primers*

Priming mixture charged		Loading pressure (psi)	Average lead disk indentation (inches)
Identity	Weight (mg)		
Exp. No. 103	60	10,000	0.051
	65	15,000	.055
	65	20,000	.059
	65	25,000	.054
	65	30,000	.057
NOL No. 130	62	15,000	.057
	65	25,000	.056
	68	40,000	.064
	70	60,000	.068
	70	80,000	.063

Gas volume and impulse measurements (page 9–42). As stated earlier, stab primers are used by the Navy for the purpose of accomplishing mechanical work. For that reason, gas volume and impulse values for Primer Mk 102 Mod 0 are of interest. The following values were obtained with Test Set Mk 175 described on page 9–42.

Primer Mk 102 Mod 0	Inches of mercury
Gas volume	2.97
Impulse	9.0

The value shown for impulse is the peak height to which an explosion of the primer forces a column of mercury. The gas volume value is the height at which the mercury comes to rest after the explosion gases cool. The gas volume value corresponds to the evolution of 10.48 cc of gas, a value which is in close agreement with the calculated theoretical amount of 10.15 cc.

Effect of input on output. The effect of input on the output of Primer Mk 102 was studied by dropping a two-ounce ball on standard issue primers from five different heights and determining the indentation, resulting from the explosion of the primer, in the supporting lead disk. Fifty primers were fired from each height. The results are as follows:

Height of drop (inches)	Average depth of indentation (inches)
2	0.0571
4	.0573
6	.0601
8	.0532
10	.0578

The test results show no significant difference in the output of the primers initiated by the ball falling from various heights.

Section 2: Percussion Primers

General Perfomance Characteristics

A percussion primer is an initiating element containing an impact-sensitive explosive charge arranged so that it will function when struck by a firing pin. Such primers are usually designed to fire when the firing pin dents the metal primer case. This type of primer is particularly suitable for use with sealed (obturated) delay elements, since initiation may be effected without breaking the seal.

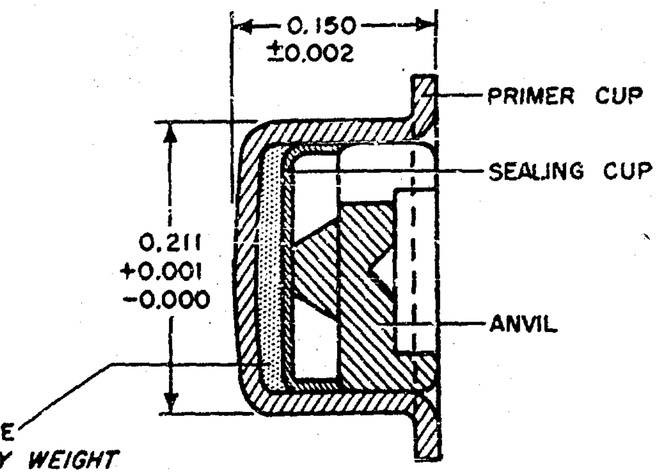
The firing pin may be driven by mechanical forces resulting from gas pressure, spring action, inertia, or direct impact. Although the use of the percussion primer has the advantage of reliability and simplicity that is often possible with mechanical arrangements, it has the limitation of requiring initiating energies that are relatively high when compared to those necessary for stab primers and detonators.

The output of a percussion primer is normally a flash or spit having low brisance. This characteristic makes percussion primers suitable for initiating delay columns, since the disrupting tendency is small, but unsuitable for initiating high explosives. Percussion primers may be used for initiating black powder, as in a black powder delay; primary explosives, as in a flash detonator; or pyrotechnic igniters, as in a gasless delay.

Applications. The Navy fuze Primer Mk 101, shown in figure 3-5, is used in base detonating Fuzes Mk 19, Mk 20, Mk 21, Mk 28, Mk 31, Mk 36, Mk 48, Mk 162 Mod 0, Mk 164 Mod 0, and Mk 165 Mod 0. This primer is initiated by a firing pin that may be driven by gas pressure, spring action, or inertia. The function of this primer is to ignite a black powder delay pellet or to cause initiation of a detonator.

The Navy percussion fuze Primer Mk 105, shown in figure 3-6, is used in Fuzes Mk 228 Mod 0, Mk 243 Mod 0, and Mk 244 Mod 1. This primer is initiated by a firing pin that is driven by inertia or direct impact. The function of the primer is to ignite a black powder delay pellet.

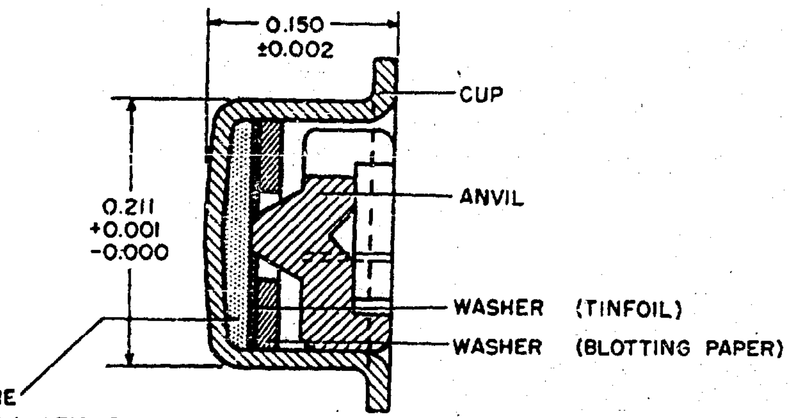
The Navy percussion fuze Primer Mk 106, shown in figure 3-7, is used in Fuzes Mk 145 Mods 0 and 1, and Mk 165 Mod 1. This primer is initiated by a firing pin that is driven by inertia. The function of the primer is to ignite a black powder delay element or to initiate a detonator.



PRIMING MIXTURE

PERCENTAGE BY WEIGHT		
FULMINATE OF MERCURY	31.25%	±0.3%
POTASSIUM CHLORATE	37.50%	±0.3%
ANTIMONY SULFIDE	31.25%	±0.3%
WEIGHT OF CHARGE	0.021 ±0.002	GRAM

Figure 3–5. Primer Mk 101 Mod 0.

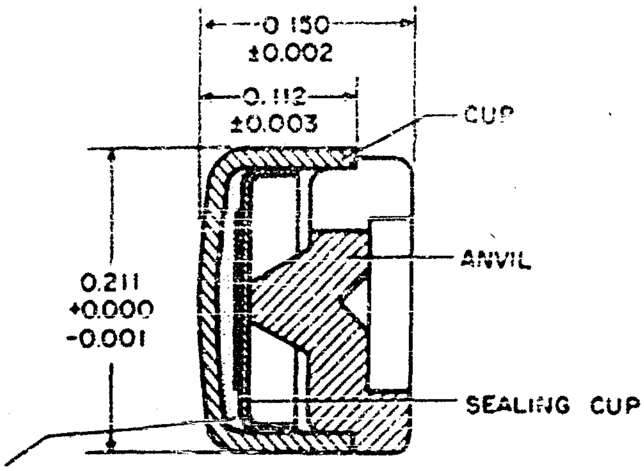


PRIMING MIXTURE

PERCENTAGE BY WEIGHT		
FULMINATE OF MERCURY	31.25%	±0.3%
POTASSIUM CHLORATE	37.50%	±0.3%
ANTIMONY SULFIDE	31.25%	±0.3%
WEIGHT OF CHARGE	0.021 ±0.002	GRAM

Figure 3–6. Primer Mk 105 Mod 0.

A typical Army percussion fuze primer is Primer M29, shown in figure 3–8. This primer is used in point detonating Fuzes M48, M51, and M51; in mechanical time Fuzes M43 and M67; and also in concrete piercing Fuze M78. This primer is initiated by a firing pin driven by spring action or by inertia. The function of the primer is to ignite a black powder delay pellet or black powder charge.

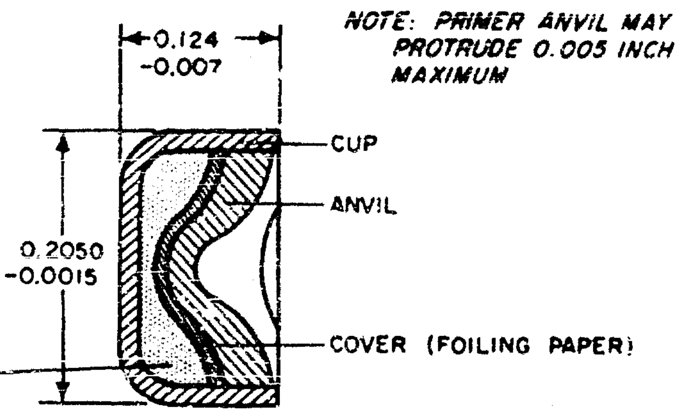


PRIMING MIXTURE
PERCENTAGE BY WEIGHT

FULMINATE OF MERCURY	31.25%	±0.3%
POTASSIUM CHLORATE	37.50%	±0.3%
ANTIMONY SULFIDE	31.25%	±0.3%

WEIGHT OF CHARGE 0.021 ±0.002 GRAM

Figure 3-7. Primer Mk 106 Mod 0.



FA 70
PRIMING MIXTURE
PERCENTAGE BY WEIGHT

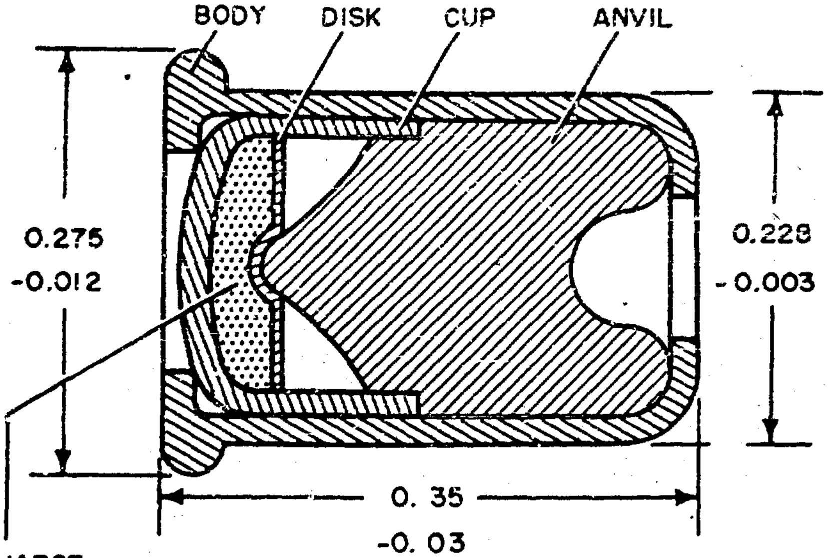
LEAD SULFOCYANATE	25%
ANTIMONY SULFIDE	17%
POTASSIUM CHLORATE	53%
TRINITROTOLUENE	5%

WEIGHT OF CHARGE
0.027 ±0.002 GRAM

MOISTEN 6 LB BATCH WITH 350 CC OF THE FOLLOWING SOLUTION:
33.3% GUM TRAGACANTH, 60 GMS
61.1% ACACIA (GUM ARABIC), 110 GMS
5.6% GELATIN GLUE, 10 GMS
WATER, DISTILLED 3,000 CC.

Figure 3-8. Primer M29.

Primer New No. 4 (percussion) is shown in figure 3-9. This primer, used in Army bomb Fuzes M100 and M103, is initiated by a firing pin that is driven by inertia upon impact of the bomb. The function of the primer is to ignite a black powder delay pellet.



PRIMER CHARGE

PERCENTAGE BY WEIGHT

ANTIMONY SULFIDE 30% ± 2%

MERCURY FULMINATE 35% ± 2%

POTASSIUM CHLORATE 35%

WEIGHT OF CHARGE 0.025 GRAM

Figure 3–9. New No. 4 Primer (Percussion).

Construction

General characteristics. The percussion primer is, in general, a small explosive element consisting of a cylindrical metal container or cup into which a small explosive charge is pressed. The charge is covered with a paper or metallic closure and assembled with an anvil.

The primer cup, or body, is constructed of a metal having a specified thickness and hardness such that when the bottom, or dome, of the primer receives an impact from a round-end firing pin, the primer will be initiated without rupture or blow-back at the point of indentation.

Suitable primary explosives. The explosive charge for percussion primers is usually a mixture consisting of a primary explosive ingredient together with an oxidizer, a fuel, and in some cases an abrasive. Explosive mixtures, however, are being used that are made up of nonexplosive components that, as a mixture, make a suitable priming composition. The more important priming mixtures now being used by the Army and Navy are presented in table 2–3 (page 2–10).

Pure primary explosives have not been used alone in percussion primers because none has been found that meets both the input and output requirements.

Sealing of percussion fuze primers. Sealing of Primers Mk 1[illegible] Mod 0 and Mk 106 Mod 0 is partially accomplished by the use of a metallic sealing cup that is placed adjacent to the priming charge prior to assembly with the anvil. One drop of wax-free shellac solution is applied by allowing it to flow through the spit holes of the anvil after the assembly of the primer is complete.

Army and some Navy fuze primers are partially sealed with a shellac-coated foiling paper that is placed adjacent to the priming charge prior to assembly with the anvil. Data on the relative sealing effectiveness of a number of sealants are presented in reference (18).

Metals for components. The components of Navy percussion fuze primers containing fulminate priming mixture usually consist of a copper primer cup, a tin sealing cup or disk, and a tin-plated brass anvil. Cartridge brass is used by the Army and in some cases by the Navy for their percussion primer cups and anvils. Gilding metal is also used by the Army for primer cups.

Recent investigations (refs. (7) and (18)) indicate that the life of a primer using a mercury fulminate priming mixture may be increased by the use of a copper sealing cup to replace the tin sealing cup.

Effect of Mechanical Details on Input Characteristics

Effect of firing pin contour. A study of the effect of firing pin contour on primer sensitivity was carried out by Frankford Arsenal, (ref. (8)). Standard caliber .30, .45, and .50 percussion primers were drop tested using direct center blows with pins of the following radii:

Pin	Radius (inches)	Pin	Radius (inches)
Flat (0.077 inch dia)	Infinite (corners 0.014 inch)	Std cal .50	0.0395
		Std cal .30	.0375
		Intermediate sharp	.0234
Std cal .45	0.0455	Sharp	.0225

It was found that these variations in firing pin contour had little effect on the sensitivity of caliber .30, .45, and .50 primers.

Tests were conducted at the Naval Ordnance Laboratory to determine the effect of firing pin contour on the sensitivity of Navy percussion Primers Mk 101. The primers used in the test had an experimental styphnate priming charge and copper sealing cups. The modified primers were reproducible in sensitivity and output. In all cases, the diameter of the shank of the firing pin was twice the radius on the point. The results are summarized in the following tabulation.

Firing pin radius (inches)	50% firing height (inches)	Standard deviation (inches)	Average relative energy output (thermocouple)
0.030	2.86	0.60	0.310
.045	2.98	.48	.348
.049	2.81	.53	.329
.060	2.79	.53	.309
.079	2.86	.30	.284

The test results indicated that the radius of curvature of the firing pin within the range tested had no effect on the sensitivity of the primer and had very little if any effect on the output of the primer as determined by thermocouple measurements.

Effect of eccentric firing pin blows on sensitivity. The variation of sensitivity with eccentricity of firing pin blow was studied in an investigation conducted at the Frankford Arsenal (ref. (9)).

Retaining firing pin plates were constructed for the drop test machine to give blows eccentric by 0.02 inch and 0.04 inch. Drop tests were made on caliber .30, .30 carbine, .45, and .50 primed cases, and on caliber .30 and .50 loose primers.

The following data on the caliber .45 primed case are typical of the results obtained. They show that little if any change in sensitivity occurs with firing pin blows of 0.02 inch eccentricity, while there is a decided decrease with blows of 0.04 inch eccentricity.

Drop weight	Eccentricity (inches)	Mean critical height [1] (inches)	Standard deviation (inches)	Drop weight	Eccentricity (inches)	Mean critical height [1] (inches)	Standard deviation (inches)
4 oz.	0.00	3.70	0.50	2 lb.	0.00	0.672	0.11
4 oz.	.02	3.79	.51	2 lb.	.02	.648	.12
4 oz.	.04	5.11	.82	2 lb.	.04	.838	.12

[1] Approximately 50 percent firing.

Effect of covering between anvil and charge. Variations in types of materials and designs for sealing cups and disks in Navy Primer Mk 101 Mod 0 have led to considerable differences in sensitivity. Some of the variations in materials and designs with the resultant sensitivities are listed in the following table.

Type of sealing assembly	Thickness of material (inch)	Bruceton sensitivity (4-oz. ball)	
		50% Firing height (inches)	Standard deviation (inches)
Paper disk	0.003	1.95	0.41
Tin disk	.005	3.74	.34
Copper disk	.005	4.04	.56
Tin sealing cup	.005	4.00	.63
Copper sealing cup	.005	4.73	1.26

Table 3–6 shows the results of a test of copper sealing cups with straight sidewalls, which were work hardened and then annealed to various degrees of hardness. These copper sealing cups were assembled in charged Mk 101 primer bodies at 60 pounds dead load and the sensitivity of the primer determined by the Bruceton drop-weight method.

TABLE 3–6.—*Effect of Sealing Cup Hardness on the Sensitivity of Percussion Primers*

Vickers hardness (1kg wt.)		Bruceton sensitivity (4-oz. ball)	
Range	Average	50 percent firing height (inches)	Standard deviation (inches)
96–117	10[illegible].7	4.84	0.52
75.2–88.2	8[illegible]	4.98	[illegible]
60.6–68.1	61.8	4.62	[illegible]
28.3–38.0	31.2	4.54	.63

The data indicate that the hardness of the copper sealing cups (0.005 inch thick) has no significant effect on primer sensitivity.

The effect of variation in the thickness of copper sealing cups on the sensitivity of Navy Primer Mk 101 is shown in the following table.

The bottoms of straight wall annealed copper sealing cups were ground to various thicknesses, the cups were assembled into Mk 101 charged primer bodies, and the resultant primers were subjected to Bruceton sensitivity tests. The test data show that the sensitivity of the primer is increased by decreasing the thickness of the metal between the anvil point and the priming mixture, that is, the bottom of the sealing cup.

Thickness of sealing cup bottom (inches)	Bruceton sensitivity (4-oz. ball)	
	50 percent firing height (inches)	Standard deviation (inches)
0.002	3.88	0.69
0.003	4.39	.64
0.004	4.83	.91
0.005	5.00	.98

Effect of firing pin velocity. In an effort to obtain some data on the effect of firing pin velocity on the energy required to initiate percussion primers, the variation of the 100-percent firing height of primers with different weight drop balls was determined on a standard primer test machine. In this test, the drop height was increased in ½-inch steps until 25 consecutive fires were obtained at one height.

An attempt was then made to obtain 25 consecutive fires at a height ¼-inch lower than this height. If this attempt was successful, the lower height was accepted, if not, the upper one was taken as the 100-percent firing height. The data are presented in table 3–7 and in figure 3–10.

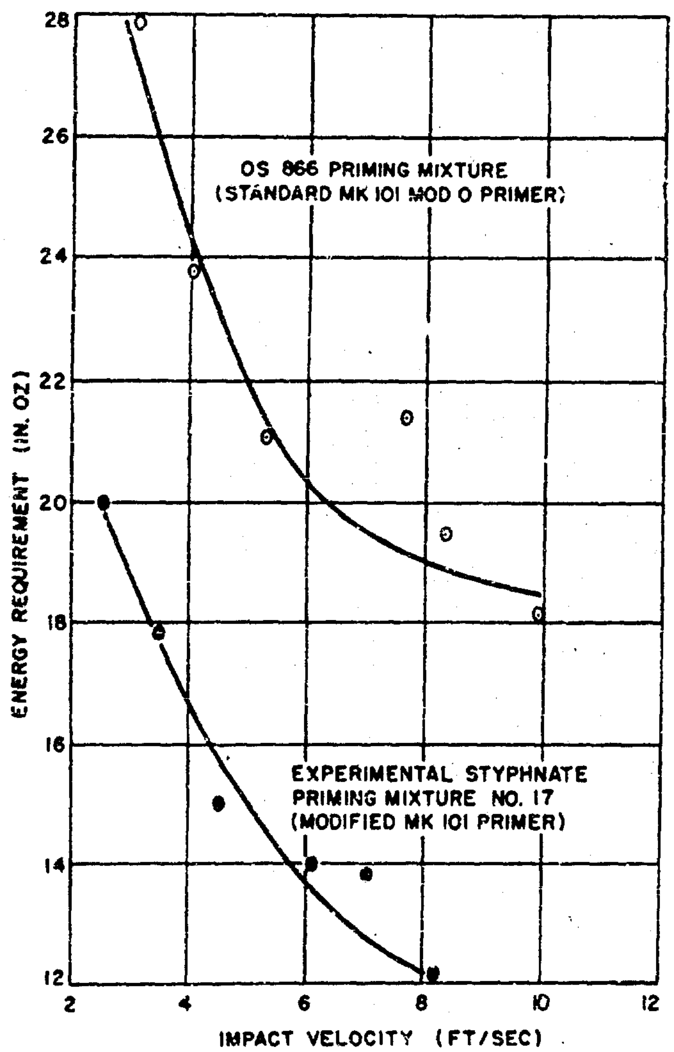


Figure 3–10. The Effect of Impact Velocity on the Energy Required to Fire 25 Consecutive Samples.

Although it is difficult to determine actual firing pin velocities in this case, the data show that the energy in inch-ounces required to initiate the primer is considerably less if the impact velocity of the ball on the firing pin is high. This fact doubtless reflects the effect of firing pin velocity on the energy required for initiation.

TABLE 3-7.—*Effect of Firing Pin Velocity on the Energy Required to Initiate Mk 101 Type Percussion Primers*

Priming mixture	Weight of drop ball (ounces)	Drop height required to fire 25 consecutive samples (inches)	Impact velocity (ft/sec)	Firing energy (in oz.)
OS 866 priming mixture (standard Mk 101 Mod 0 primer).	0.99 1.50 2.00 3.99 7.95 15.97	18.25 13.00 10.75 5.25 3.00 1.75	9.90 8.34 7.62 5.32 4.01 3.11	18.1 19.5 21.5 20.9 23.8 27.9
Experimental styphnate priming mixture No. 17 (modified Mk 101 primer).	0.99 1.50 2.00 3.99 7.95 15.97	12.25 9.25 7.00 3.75 2.25 1.25	8.10 7.04 6.11 4.47 3.50 2.59	12.1 13.9 14.0 15.0 17.9 20.0

It is concluded that the situation here is similar to that for stab primers (page 3-7); and that initiation will fail to occur where (1) the rate of transfer is low even though the total energy is large; and (2) where the energy is low, even though the rate of transfer is high.

Effect of unevaluated mechanical details. The thickness and hardness of the primer cup in the area where it is struck by the firing pin is important from the standpoint of sensitivity; however, no quantitative data are available. Qualitatively, it can be said that the harder and thicker the cup, the lower the sensitivity. In designing a percussion primer to obtain maximum sensitivity, therefore, one should use the thinnest and softest primer cup consistent with blowback-free functioning. Blowback of a percussion primer occurs when the explosion of the primer ruptures the bottom or dome of the primer cup by blowing through the indentation made by the firing pin.

From the standpoint of sensitivity, the thickness of the explosive layer between the point of the anvil and the primer cup in the area where it is struck by the firing pin is probably important. Although no data are available, experience indicates that for maximum sensitivity this thickness should be the least that is consistent with reasonable surety that ample explosive is present in the area where the two parts come together on firing pin impact.

Anvil movement on firing pin impact will decrease the sensitivity of a percussion primer an indefinite amount. Movement of the anvil in the percussion primer may be a hazard in the handling of the assembled fuzes. It has been found that in some cases primers assembled in plummets without firing pins, when dropped from a height of 27 feet, fired due to anvil movement. The design should be such that after the primer is assembled into a fuze mechanism, little or no movement of the anvil is possible.

Effect of Loading Pressure on Input Requirements

Two types of priming mixtures were loaded into Navy Primers Mk 101 at pressures from 10,000 to 60,000 psi in 10,000 psi increments. The primers were assembled with shortened copper sealing cups (BuOrd Drawing 893576) and anvils, then they were subjected to a Bruceton sensitivity test.

The test data given in table 3–8, indicate that there is no important variation of sensitivity with loading pressure.

TABLE 3–8.—*Effect of Loading Pressure on Sensitivity of Priming Mixtures Used in Percussion Primers.*

Priming mixture, 21 mg	Loading pressure (psi)	50 percent firing height (inches)	Standard deviation (inches)	Average relative energy output (thermocouple)
OS 866 priming mixture	10,000	3.63	0.42	0.376
	20,000	3.50	.53	.374
	30,000	3.23	.42	.376
	40,000	3.42	.50	.390
	50,000	3.51	.48	.385
	60,000	3.79	.37	.376
Experimental styphnate priming mixture No. 84 [1]	10,000	3.47	.61	.351
	20,000	3.17	.39	.355
	30,000	2.87	.49	.368
	40,000	2.91	.65	.343
	50,000	3.07	.92	.338
	60,000	2.89	.57	.334

[1] Composition of Experimental styphnate priming mixture No. 84:

	Percent
Basic lead styphnate	20
Barium nitrate	35
Antimony sulfide	22
Tetracene	5
RDX	18

Effect of Amount of Charge on Output

The output of a primer is dependent to a large degree upon the charge weight. Experiments have been carried out at the Naval Ordnance Laboratory on Modified Navy Primer Mk 101 assembled with shortened copper sealing cups to determine the variation of thermocouple measurements, delay times, impulse, and gas volume readings with increasing charge weight in the primer. The results are presented in table 3–9 and in figures 3–11 and 3–12. The data show that thermocouple, impulse, and gas volume measurements increase with increasing charge weight, and that delay times decrease with increasing charge weight.

A discussion of the test methods used (with the exception of the delay element test) is given in chapter 9. A brief description of these methods follows.

Thermocouple measurements are made by placing the junction of the thermocouple wires in the flame of the primer and amplifying the

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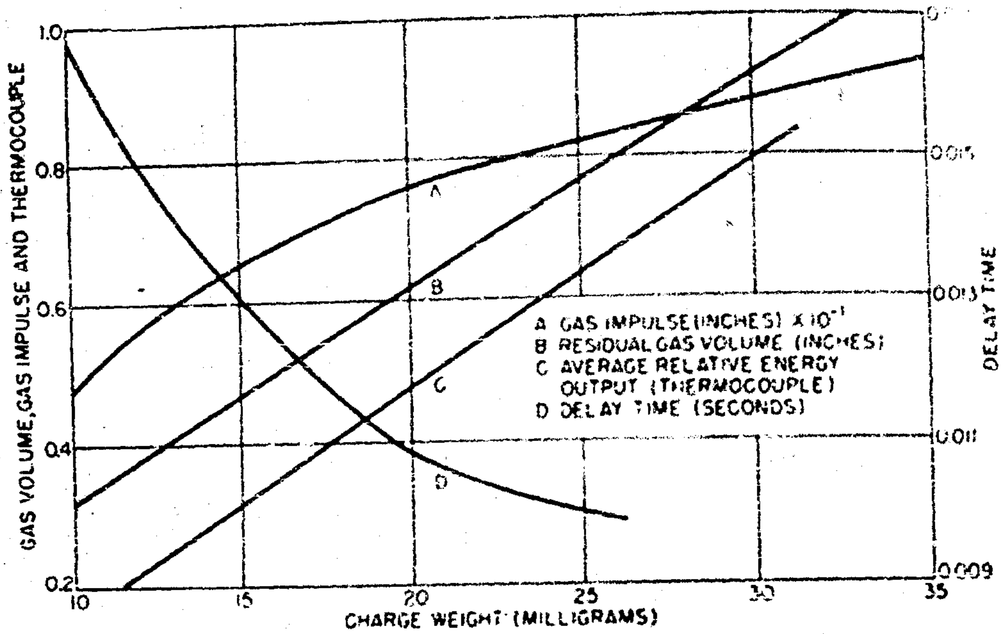

Figure 3-11. Effect of Charge Weight on Output Characteristics of Modified Navy Primer Mk 101 Assembled with Shortened Copper Sealing Cups. OS 866 Priming Mixture.

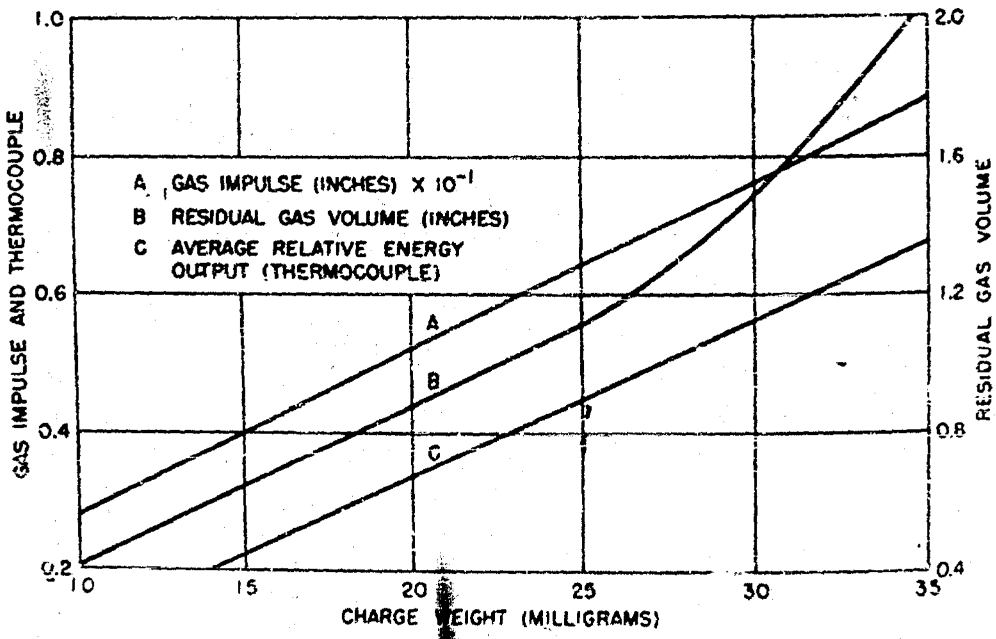

Figure 3-12. Effect of Charge Weight on Output Characteristics of Primers Mk 101 Assembled with Shortened Copper Sealing Cups. Experimental Styphnate Priming Mixture No. 17.

TABLE 3–9.—*Effect of Charge Weight on Output Characteristics of Modified Navy Primer Mk 101 Assembled with Shortened Copper Sealing Cups*

Charge	Charge weight (mg)	Average relative energy output (thermocouple)	Delay time [1] (seconds)	Gas impulse (inches)	Residual gas volume (inches pressure)
OS 866 priming mixture	10	0.252	0.0168	4.72	0.32
	15	.371	.0130	6.55	.49
	20	.440	.0108	7.61	.62
	25	.576	.0100	8.22	.77
	30	.816	----------	8.94	.88
	35	----------	----------	9.51	1.11
Experimental styphnate priming mixture No. 17.[2]	10	.143	----------	2.77	0.41
	15	.225	----------	4.10	.65
	20	.314	----------	5.20	.88
	25	.456	----------	6.46	1.11
	30	.568	----------	7.84	1.57
	35	.661	----------	8.79	1.98

[1] Burning time of a nominal 0.01 second black powder delay when ignited by the primer.
[2] Composition of experimental styphnate priming mixture No. 17:

	Percent
Basic lead styphnate	20
Barium nitrate	35
Antimony sulfide	20
Tetracene	5
RDX	20

voltage generated with a chopper amplifier. The amplified voltage is measured with a peak voltmeter. This voltage is a function of the total thermal energy released by the primer, provided the response time of the thermocouple is long compared to the duration of the flame.

Impulse and gas volume measurements on percussion primers are obtained by firing the primer in a closed chamber which is separated from a mercury reservoir by a rubber diaphragm. The impulse of the initiated primer expands the rubber diaphragm and drives the mercury from the reservoir up a capillary tube. The height to which the mercury is raised in the tube is measured and serves as an estimation of the impulse.

After the initial impulse, the mercury drops in the tube to a point at which it remains. This measurement indicates the residual gas volume of the primer. The impulse is used as an indication of brisance, while the residual volume is an indication of the amount of permanent gas formed by the functioning of the primer.

The measurement of the time of burning of the delay elements of fuzes is accomplished by means of a specially designed apparatus for holding and firing the complete time train, including primer, delay element, and detonator. A Potter electronic counter or other suitable timing device is used for recording the time intervals.

If the Potter counter is used, the firing pin striking the primer in the delay train closes a circuit that starts the counter. When the detonator at the end of the train fires, it causes a voltage change between two probes which closes another circuit and stops the timer.

The time elapsing between the firing pin striking the primer and the firing of the detonator is called the delay time. This value is used as a criterion of primer performance from the standpoint of igniting delays. In general, the more powerful primers give shorter delay times.

Effect of Amount of Initiating Energy on Output

Experiments were carried out to determine the effect of the amount of initiating energy on output as measured by thermocouple readings.

The percussion primers tested were Mk 101 type primer cups assembled with a copper sealing cup and containing a styphnate priming mixture.

As shown in the following table, the tests indicate that there is no increase in output, as measured by thermocouple readings, with an increase in initiating energy. These results should not be accepted as indicative of the behavior of percussion priming mixtures in general. Experience indicates that priming mixtures containing little or no primary explosive tend to give low order functioning when the initiation is marginal.

Drop height (inches)	Relative energy output[1] (thermocouple)
4	0.430
8	.499
12	.494
16	.488
20	.480

[1] Average of 50 readings.

Effect of Loading Pressure on Output

Tests carried out on fulminate and styphnate priming mixtures indicate that loading pressure has no appreciable effect on output as measured by thermocouple readings. This fact is shown in table 3-8 (page 3-19).

Section 3.—Electric Primers

General Performance Characteristics

The primary function of a primer is to intiate action of the explosive train at the proper instant. Most frequently this is at the moment of impact of the fuze with the target; in the newer electric type fuzes, however, this need not be the case, as firing may occur without impact.

Electric primers are fired by an electrical pulse supplied by the fuze in which the primer is used. The energy is either stored within the fuze before release of the fuze-bearing missile, or generated within

the fuze system just prior to or at impact of the fuze.

An electric primer expends itself in effecting ignition of the next component of the train, which is normally a detonator or a delay.

Advantages. The advantages electric primers possess over either the stab or percussion varieties are inherent because electrical energy is so readily generated, stored, amplified, and switched.

On comparing the energy necessary to fire an electric primer with that required for the stab or percussion type, one finds a decided advantage in favor of the electric primer. Consistent firing at energy inputs of 100 ergs or less is easily obtainable. On the other hand, the most sensitive mechanical primers require about 50,000 ergs for firing. Development of one proximity fuze was feasible because weak electrical signals could be easily amplified and because the low-energy characteristic of certain electric primers could be utilized.

Electric fuzes may incorporate features of selectivity or discrimination. In many fuzes utilizing delay action, it is often found desirable either to preselect one of a series of desired delays or to have the fuze itself select one particular delay from a set series, depending on the type of target it strikes. There may, for example, be one delay for water impact and a different delay for metallic impact. By proper design of the electric firing circuits, the use of low-energy primers, and the use of a magnetic generator or a properly charged storage condenser, the feature of selectivity or discrimination may be obtained.

Another important advantage of the electric primer is that, because of the high speed of transmission of an electric signal, primer action may be made practically simultaneous with some remote event. For instance, it may be desirable to start action of the fuze train at the moment of nose impact but at the rear of the fuze, or to transmit the action to the rear of the main charge instantaneously. These accomplishments offer no serious problem in electrical fuzing but would be quite complicated in mechanical designs.

In some respects, the electric primer has a safety advantage over the stab or percussion type. It is evident that the latter types must have some portion which is sensitive to a blow or a prick, such as may occur in handling. On the other hand, the electric primer can be made insensitive from this standpoint and at the same time can be adequately protected from any stray electric currents.

Some other advantages claimed for electric primers are: easier laboratory evaluation of their firing characteristics, more adaptability to hermetic sealing, and use in fuzes with time-interval arming rather than air-travel arming.

Limitations and disadvantages. Although a number of advantages are to be gained by the use of electric primers for special purposes, their use entails certain inherent disadvantages. Where a primer is to be used and an electric primer is not essential, much can be gained in simplicity of construction, ease of manufacture, and reliability by the use of a percussion or stab primer.

It is obvious that fuzes employing electric primers must carry along either a source of stored energy or a generator to supply the energy necessary for firing. Besides the energy source, the fuze must carry suitable electrical circuits for obtaining the selectivity, discrimination, or proximity action that is usually the ultimate goal. Electrical fuzing systems are relatively new, however, and advances are being made so rapidly that it appears that the complexity and space requirements of these components will eventually be less than those of equivalent mechanical fuzes.

Most of the electric fuze primers in current use employ a bridge wire to heat a surrounding primary explosive. These primers require only a low energy input to effect ignition (100–4,500 ergs). The problems attending the preparation of the very fine wire required to obtain such energy characteristics, the incorporation of this wire into the electrical circuit, and the wire life span are usually acute, and special techniques are required to obtain the desired results. Herein lie the chief disadvantages of electric primers, but there is good reason to believe that these disadvantages will disappear as more experience is gained in the field.

Construction

General characteristics. The instantaneous electric primer is best considered as consisting of an ignition element and a base charge assembled to form a single unit. The ignition element consists of the wire leads or contacts molded into a plug, the bridge fastened to these contacts, and a means of surrounding this bridge with a suitable sensitive explosive. The base charge in an electric primer usually consists of a quantity of sensitive explosive which is pressed into a cup and is capable of being initiated by the flash from the ignition element. The combined output of the ignition element and the base charge must be sufficient to initiate the next element in the fuze train.

Suitable primary explosives. There are a number of primary explosives that have a sensitivity suitable for use in the ignition elements of electric primers; data on these may be found in chapter 2 (page 2–3). However, the electric primer at present finds only limited use in Naval fuzes, and for this reason only two compositions

or variants of these are now being used. It is possible that neither of these may be entirely satisfactory from the stand-points of surveillance and sensitivity. These two compositions are: XC-9 (consisting of 75 percent DDNP with 25 percent $KClO_3$ ground in a 2.4 percent solution of nitrostarch in butyl acetate) and normal lead styphnate. There is some evidence that XC-9 composition does not have suitable surveillance characteristics where moisture may enter. The surveillance characteristics of lead styphnate seem to be highly acceptable.

For the base charge, Primers Mk 112, 113, 114, and 121 use DDNP/$KClO_3$, 75/25. Some experimental electric primers use a lead azide base charge.

Metals for components. Metals for components of electric primers are chosen to give compatability with the explosives used. In present primers, these metals have consisted entirely of stainless steel, copper, aluminum, or tin. In Primers Mk 112, 113, 114, and 121, only copper is in contact with the XC-9 or lead styphnate unless one wishes to consider the tophet-C bridge wire, the solder composition, and the tin coating on the leads. There is some evidence that copper, which has been used extensively with XC-9 composition, is not compatible with it in the presence of moisture. In primers that use lead azide, either aluminum or stainless steel is generally used in order to avoid formation of "supersensitive" azide salts.

Examples

Ignition element of the experimental spray metal type primer. In many of the newer fuzes employing electric primers, need has arisen for primers capable of being actuated by an extremely small energy input. To meet this requirement with the metal bridge wire system commonly employed in the electric primer, it has been necessary to employ bridge wires of small diameters and lengths in order that the small quantity of energy delivered to the bridge will be sufficient to heat it to the temperature necessary to initiate the surrounding explosive. For a 100-erg primer using tungsten wire, the diameter may be as small as 87 microinches or less with lengths in the order of 15 thousandths of an inch. Special techniques have been found necessary to prepare wire of this diameter and to secure it both mechanically and electrically to the primer leads or contacts (ref. (10)). An experimental primer, designated spray metal type, in which these techniques have been employed, has been developed. Figure 3-13 is a general arrangement drawing of this type of primer.

The term "spray metal" refers to a special method of attaching the fine wire, which was originated by the Naval Ordnance Laboratory. A stream of atomized molten metal is directed toward the wire at the

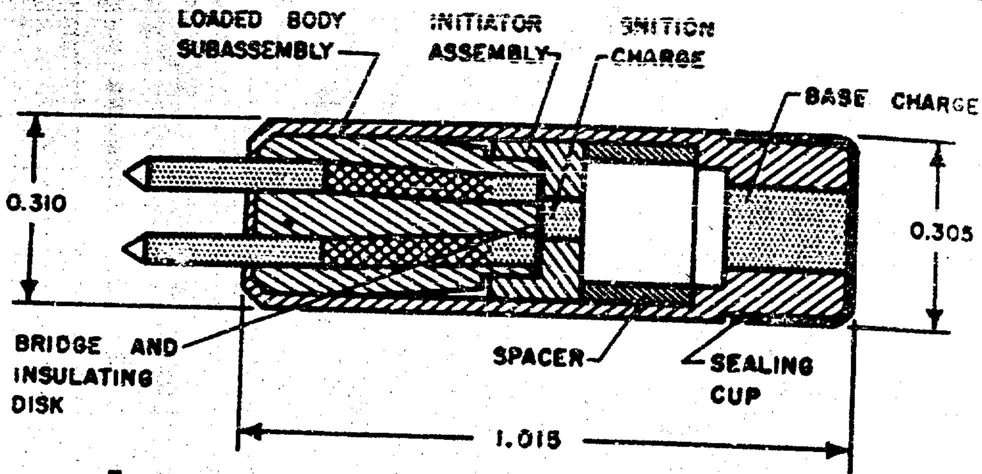

Figure 3-13. Experimental Spray Metal Electric Primer.

place where it meets the contact prongs. The solidifying metal attaches itself to both the prong and the wire, forming the necessary junction. Only the length of wire required for the bridge is shielded from the spray metal.

The ignition element consists of the primer plug, the bridge wire attached by spray metal, the charge holder, and the flash charge pressed in the charge cavity.

The primer plug consists of a set of contacts molded into a general phenolic molding compound. Drawings of the contact prong and the plug are shown in NOL Sketches 76924 and 71357, respectively. In practice, the prong is made of properly tempered phosphor bronze or brass. After the molding process, the prong end is cut off, leaving two contact terminals. Before the spraying operation, the phenolic plug surface is roughened in order that the spray metal will adhere to it more readily. The bridge wire is then attached, and the charge holder is forced down on the plug nose. The charge holder and the washer necessary to insulate it from the spray metal are shown in NOL Sketches 125228 and 125291. After the charge holder is attached, the cavity is loaded with 5 milligrams of dry lead styphnate pressed at 3,400 psi—completing the ignition element as shown in NOL Sketch 303383.

Base charge of spray metal type primer. For the instantaneous primer, the base charge is loaded into a stainless steel body as shown in NOL Sketch 125389. Loading is performed using 100 milligrams of dry lead azide pressed into the 0.1250 inch diameter hole under 65,000 psi.

The ignition element, loaded body, and sealing cup are assembled to give a completed unit as shown in figure 3-13 and NOL Sketch 303384. The ignition element is a force fit in one end of the body and the sealing

cup, a force fit on the other end. This arrangement effectively seals the unit.

Electric Fuze Primer Mk 112 Mod 0. The general arrangement of this primer is shown in figure 3–14. The ignition subassembly consists of a primer plug, a bridge wire attached by soldering, a flash charge holder, and a flash charge.

The primer plug is of general phenolic molding compound. It has molded within its structure two insulated lead wires. The plug is shown in BuOrd drawing 398506. After the leads projecting beyond the plug nose are cut to proper length, the bridge wire, which is 0.0005 inch diameter tophet-C, is soldered to the terminals. The fiber charge holder, a force fit on the nose of the plug, is attached and the flash charge, XC-9, is buttered into the charge holder and around the wire. The buttered material is allowed to dry. Its weight is approximately 60 milligrams. The completed ignition subassembly is shown in BuOrd drawing 398556.

Approximately 60 milligrams of base charge (75 percent DDNP, 25 percent $KClO_3$) is weighed into the copper cup shown in BuOrd drawing 398558. The ignition assembly is then forced into the cup and down on the base charge, compressing it to the proper length. After the cup is crimped on the ignition element, the final arrangement is as shown in figure 3–14 and BuOrd drawing 398490.

Carbon-bridge type primer. The general arrangement of the electric fuze Primer Mk 121 is shown in figure 3–15. The ignition subassembly closely resembles that of Primer Mk 112, the major difference being the replacement of the bridge wire by the conductive carbon path.

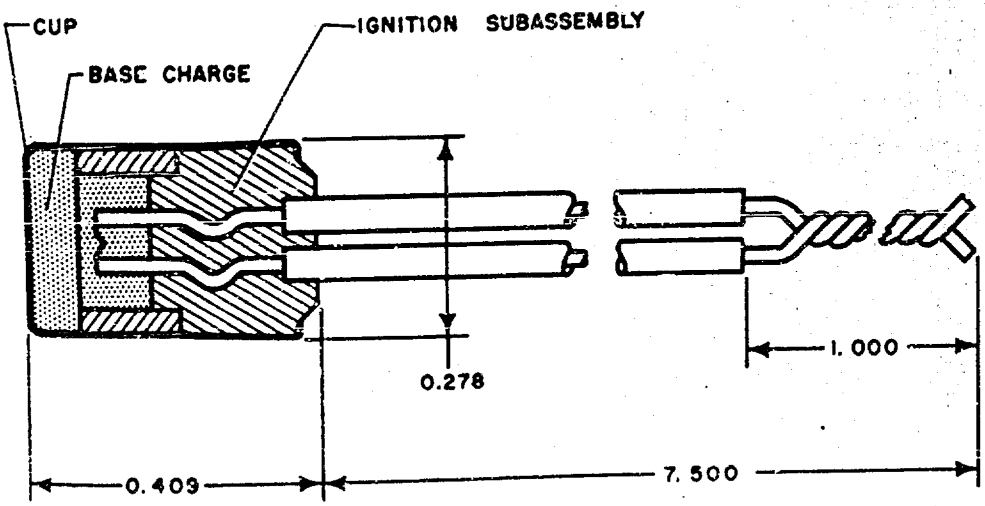

Figure 3–14. Electric Fuze Primer Mk 112 Mod 0.

The primer plug is composed of general phenolic molding compound. It has molded within its structure two copper wire leads, one or both of which may be insulated with a coating of suitable plastic insulation, such as polyvinyl acetate. These wires are twisted together with a helical twist of eleven 360° turns per inch.

After molding, the nose of the plug is ground to length with emery cloth, and the plug is heated for two minutes by an infra-red lamp. The plug is then polished under a microscope, using crocus grade abrasive, to remove any copper burrs. The surface is then cleaned by wiping with alcohol.

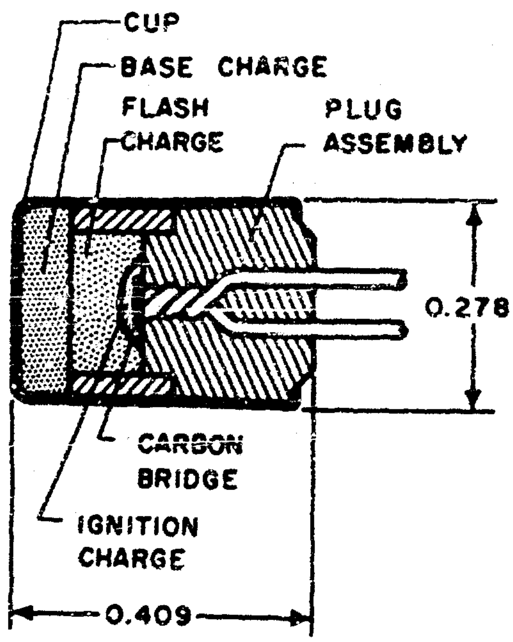

Figure 3–15. Electric Fuze Primer Mk 121.

The bridging of the gap caused by the insulation on the lead wire (or wires) is accomplished by applying a "dag" (usually aquadag) with a wire loop, keeping the coated area as small as possible consistent with a good bridge, and then drying rather rapidly under an infra-red lamp.

The charge holder is then put on; and the ignition charge, consisting of about 0.0015 gram of a mixture of ground lead styphnate and clear lacquer, is applied over the bridge with a wire loop. This is then dried; and the flash charge, of the same composition as the ignition charge, is buttered in and the assembly dried.

The base charge (loading, materials, and assembly) is identical with that for Primer Mk 112 previously described.

Effect of Bridge Dimensions on Input Characteristics of Bridge-Wire Type Primer

A detailed discussion of the firing characteristics of electric primers, with particular emphasis on those made by the spray metal process, may be found in reference (15).

The dimensions of the bridge have an important effect on input characteristics, since they affect the energy required to raise the temperature of the bridge, the rate of heat loss from the bridge wire, and the resistance of the bridge. The relationships between wire diameter and resistance per unit length for two common bridge materials, tungsten and tophet-C, are shown in figures 3–16 and 3–17, respectively. A comprehensive discussion of bridge wire temperatures resulting from the conduction of electricity may be found in reference (14).

Effect of wire volume. In igniting an electric primer of the bridge-wire variety, a quantity of electrical energy is passed through the bridge wire, where, due to the resistance of the bridge, it is converted to heat. If the temperature required for initiation of the primary explosive surrounding the bridge is attained by the bridge, the primer will be initiated. It is apparent that some of the factors determining what input is required to fire an electric primer are the mass of the wire, its specific heat, and the explosion temperature of the primary explosive surrounding the bridge. Since the wire mass is proportional to the volume, it follows that (for an explosive having a given explosion temperature coupled with a given wire material) the energy required for firing should be proportional to the wire volume. Experimental data plotted for tungsten wire with lead styphnate and for tophet-C wire with lead styphnate in spray metal type primers are shown in figures 3–18 and 3–19. These graphs give fairly good straight lines over the region shown.

For design purposes, it is perfectly feasible to use such a graph (with certain reservations), as usually only an approximate value is required; a certain amount of cut-and-try procedure is necessary in any event to bring the desired input into the exact range desired. From the foregoing discussion, one may be led to the conclusion that other things being equal, the use of a bridge material of low specific heat would permit firing with much lower energy inputs than would be required with bridge materials of high specific heat. This is not true, however, because the volumetric heat capacities of metallic substances do not differ much from each other; the ratio of the highest to the lowest being only of the order of 2 to 1. This fact is shown in table 3–10, which gives a series of metallic elements and the heat required to raise their temperatures 1000° C.

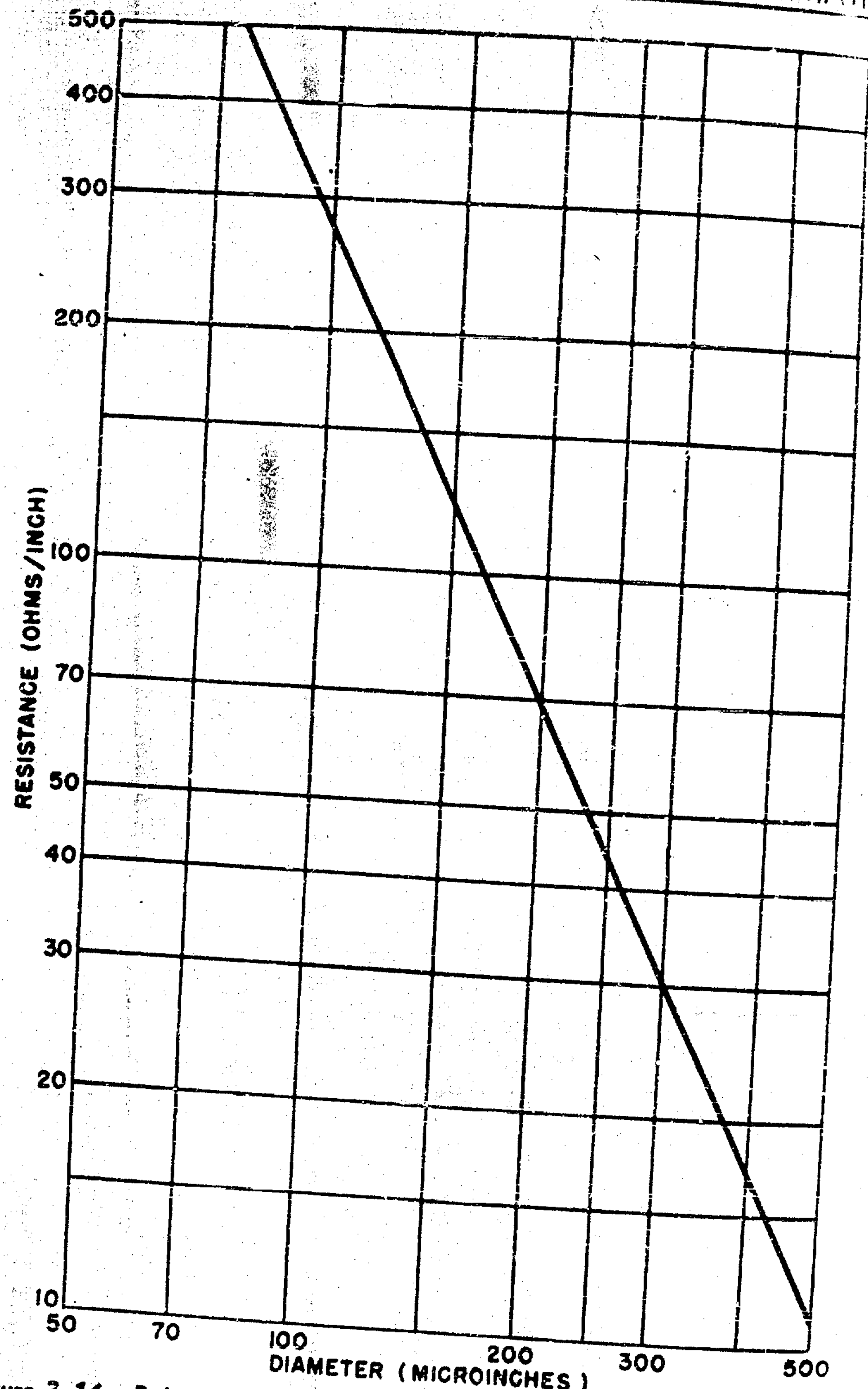

Figure 3-16. Relationship Between Wire Diameter and Resistance per Unit Length for Tungsten Wire Bridge.

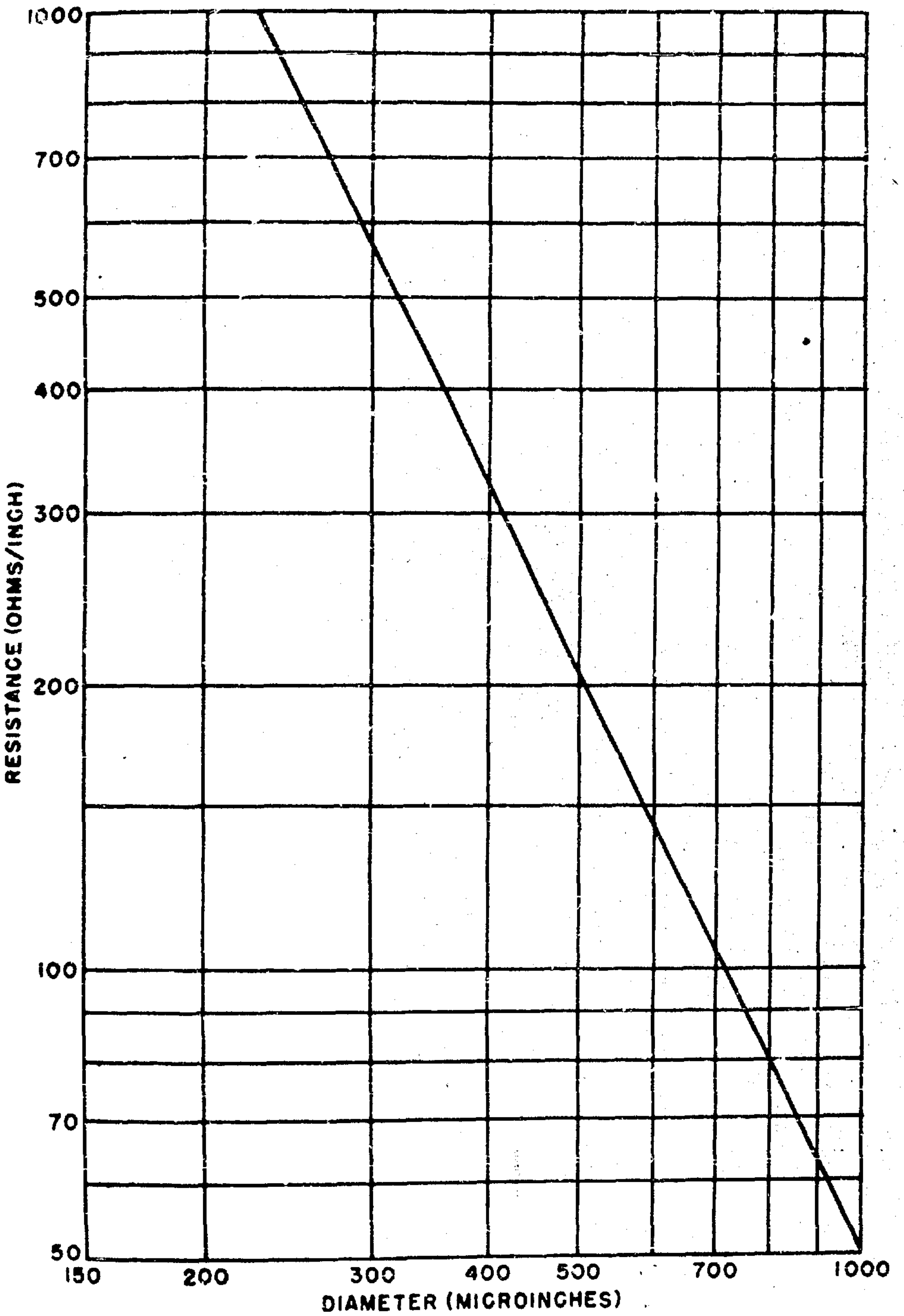

Figure 3–17. Relationship Between Wire Diameter and Resistance per Unit Length for Tophet-C Wire Bridge.

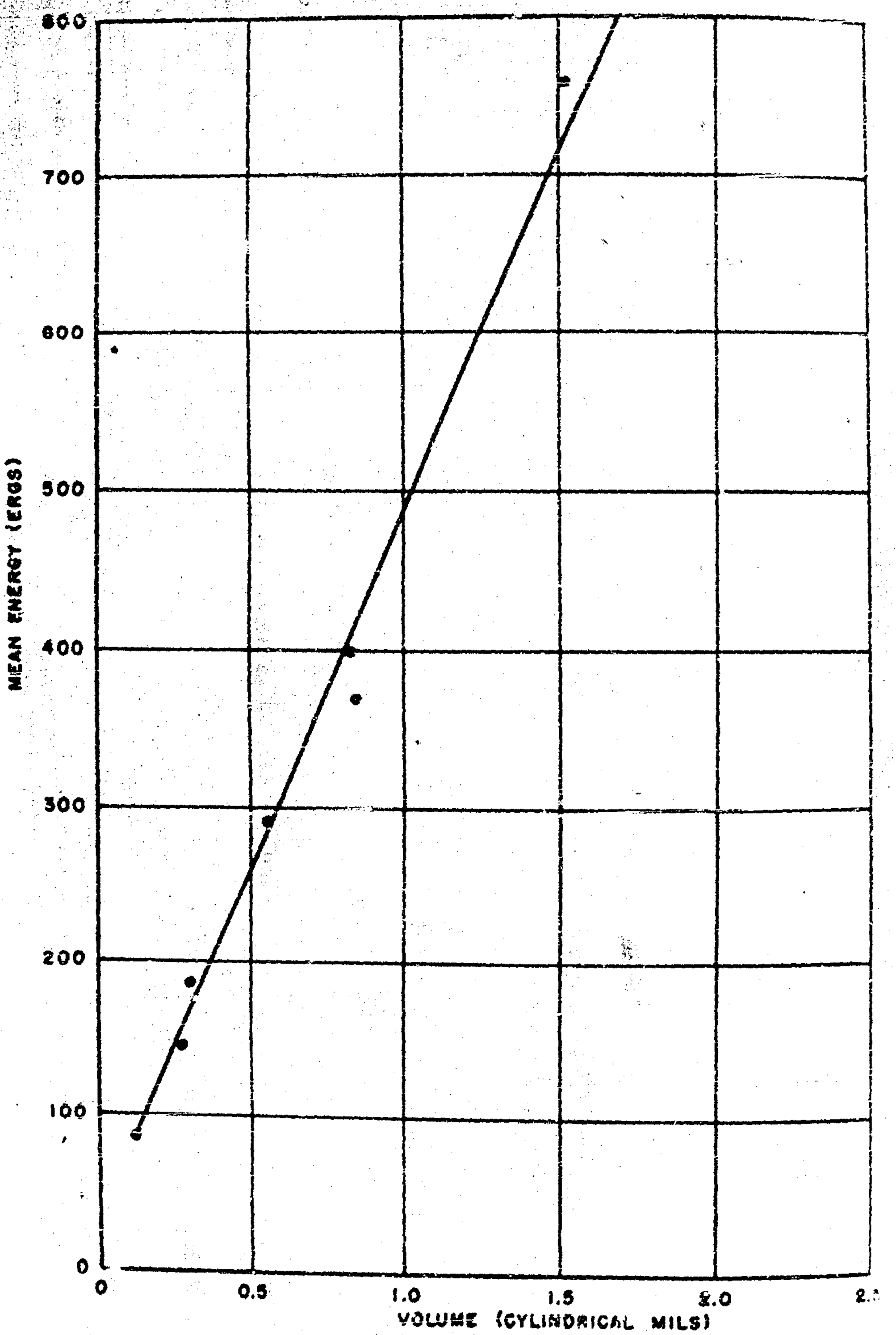

Figure 3-18. Effect of Bridge Wire Volume on Input Characteristics of Tungsten Wire Plus Lead Styphnate. 14-20 Volt Firing Potential.

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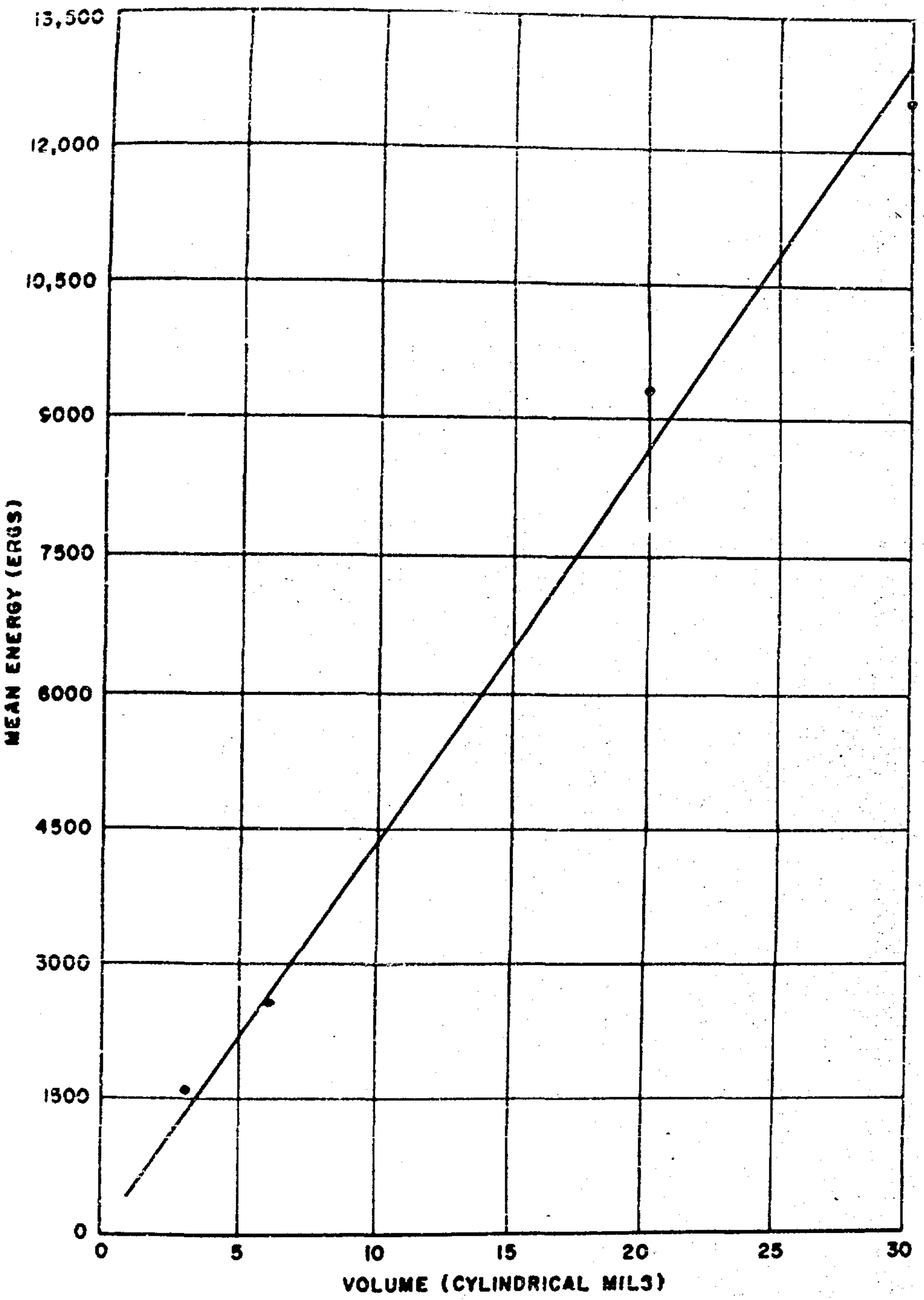

Figure 3–19. Effect of Bridge Wire Volume on Input Characteristics of Tophet-C Wire Plus Lead Styphnate. 14–20 Volt Firing Potential.

TABLE 3-10.—*Volumetric Specific Heats of Metals*

Material	Cal/cc/1000° C	Material	Cal/cc/1000° C
Cobalt	1177	Silver	633
Copper	927	Gold	620
Iron	1243	Titanium	816
Nickel	1339	Tungsten	659
Aluminum	779		

The heat was calculated by integrating the specific heat equation of form $C=A+BT$ for each element shown through a 1000 degree C interval. Crystal transitions which may occur in the useful range of 0–1000 degrees C were ignored, since the time of functioning for the electric fuze primers to be considered is normally so short that it is unlikely that these transitions will have time to occur.

The basic factors affecting the choice of wire material may usually be reduced to the following:

(*a*) adequate strength
(*b*) proper resistance
(*c*) suitable surveillance characteristics
(*d*) melting point higher than the temperature to which the explosive must be heated to effect ignition in the desired time.

Effect of wire diameter. There are several reasons why the curves shown in figures 3–18 and 3–19 should not be true straight lines. The largest single reason is that wires of different diameter need not attain the same temperature to effect ignition of the surrounding explosive. As the wire diameter increases, the required temperature, in general, will diminish. This effect is not the same for all explosives, but is rather dependent on their activation energies.

The effect of wire diameter is shown in figure 3–20, where the energy is plotted as a function of the wire diameter for several different primary explosives. It will be noted that, in general, the energy required does not fall on a line parallel to the isotherms. As the diameter increases, the temperature required for ignition, and thus the energy for a given wire volume, decreases.

Effect of wire length. A second factor which tends to make the volume vs. energy plot diverge from a straight line is the greater percent of heat conducted away from the shorter bridge wire at the points of contact with the spray metal or wire leads. For example, if one uses a wire of given diameter and measures the energy requirement for several different bridge lengths, it will be found that the longer wires require less than proportionate amounts of energy. Doubling the length of bridge does not double the required energy. There is a certain quantity of heat lost by the wire to the metal surrounding it

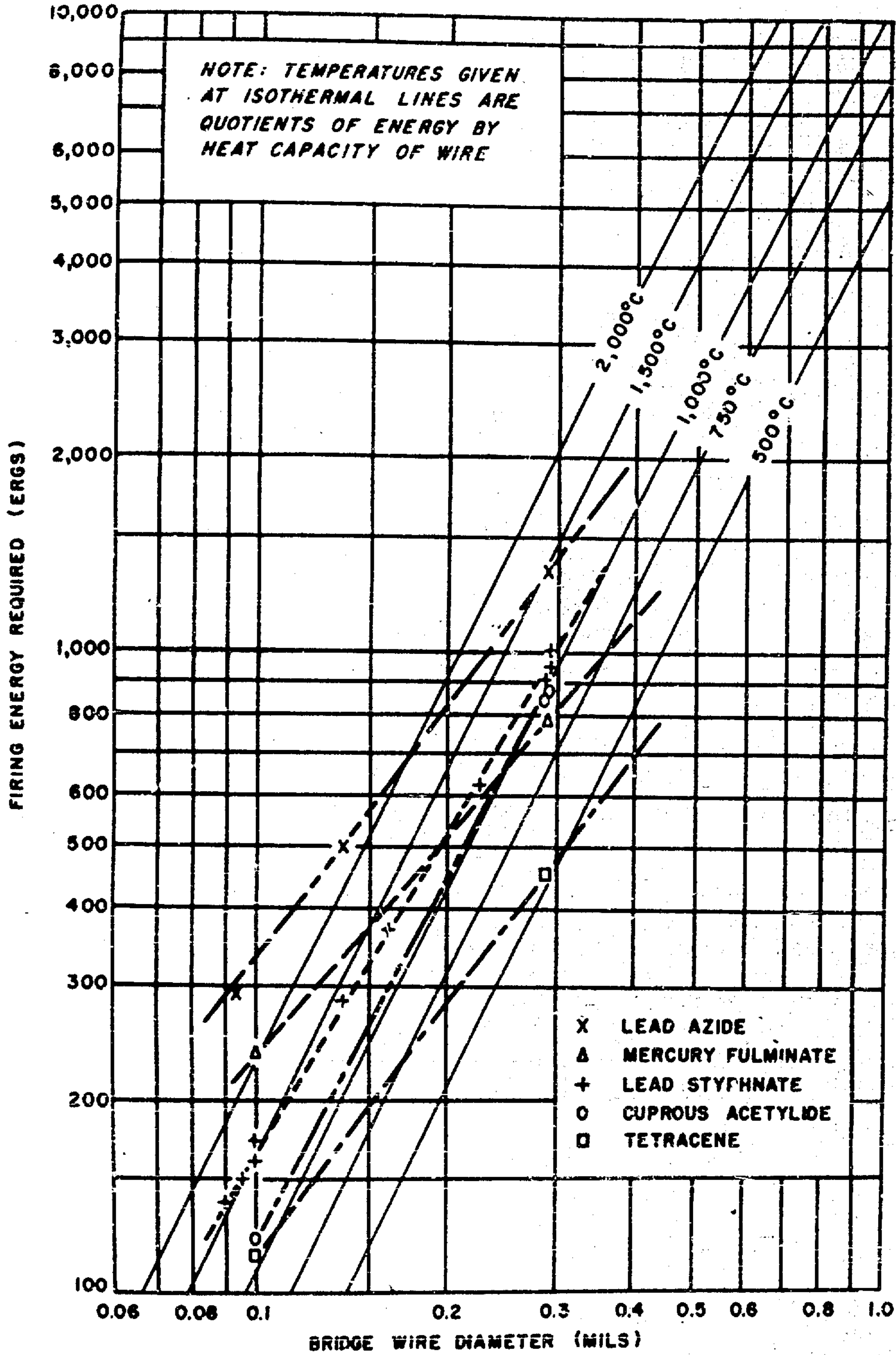

Figure 3-20. Energy Requirement vs. Bridge Wire Diameter for Spray Metal Bridged Electric Initiators. Bridge Metal, Tungsten.

at its ends. As the length of wire is increased, less energy per unit length will be required to heat it to a given temperature as the loss of energy at the wire ends becomes a smaller fraction of the total energy input. Table 3–11 presents an example of this fact as applied to spray metal type primers.

TABLE 3–11.—*Effect of Wire Length on Input Characteristics in Spray Metal Type Electric Primers*

Wire diameter (mils)	Wire length (inch)	Mean energy (ergs)
0.095	0.010	57
.095	.030	145
.087	.015	96
.087	.030	136

Effect of Rate of Energy Input in Bridge-Wire Primer

Condenser discharge circuits. Since the present mechanics for effecting ignition of electric wire type primers is that of raising a mass of wire to the explosion temperature of a surrounding explosive, it follows that any factor affecting the final wire temperature will also affect the explosion probability. The effect of wire diameter and wire length have already been discussed. There is another factor of great importance that must be reckoned with, that of the rate of energy input.

All the energy relationships given above are based on condenser discharge type circuits, wherein a condenser is charged to a given potential and then discharged through the resistance of the bridge. In such a circuit, roughly 86 percent of the energy is put through the resistance in a time given by RC, the product of resistance and capacitance. This type of circuit, or its equivalent, is the one primarily used in firing electric fuze primers. If RC is kept very short compared with the cooling time of the bridge system it will have little if any effect on the required energy, but when the RC time becomes progressively longer it finally reaches a point where the bridge wire has time to cool appreciably and the firing energy characteristic is altered. As the RC time is made still longer, the required energy for firing increases very rapidly.

For a given primer, as the firing potential is increased and the capacitance decreased, less energy will be required down to some constant minimum value; as the potential is decreased and the capacitance increased, more and more energy will be required for firing; eventually, a point will be reached where the required firing potential is the same, no matter how large the condenser. This point should correspond to the minimum potential for direct firing, as from a battery.

With increasing wire diameters, this relationship is of less practical importance because the cooling times become long compared to the pulse times ordinarily used. This relationship is shown in figures 3–21 and 3–22, which are based on the same experimental results. Figure 3–23 gives additional data on the effect of time of energy input on required energy for 50 percent firing. The estimated hot RC curve is obtained from the observation that the average resistance during firing of the low energy primer utilizing a tungsten bridge wire is approximately 3.5 times that of the measured cold resistance. This increase of resistance depends, of course, on the bridge material, being fairly large for tungsten, which exhibits a large temperature coefficient of resistivity, but small for tophet–C, which has a small temperature coefficient. In evaluating some primer characteristics,

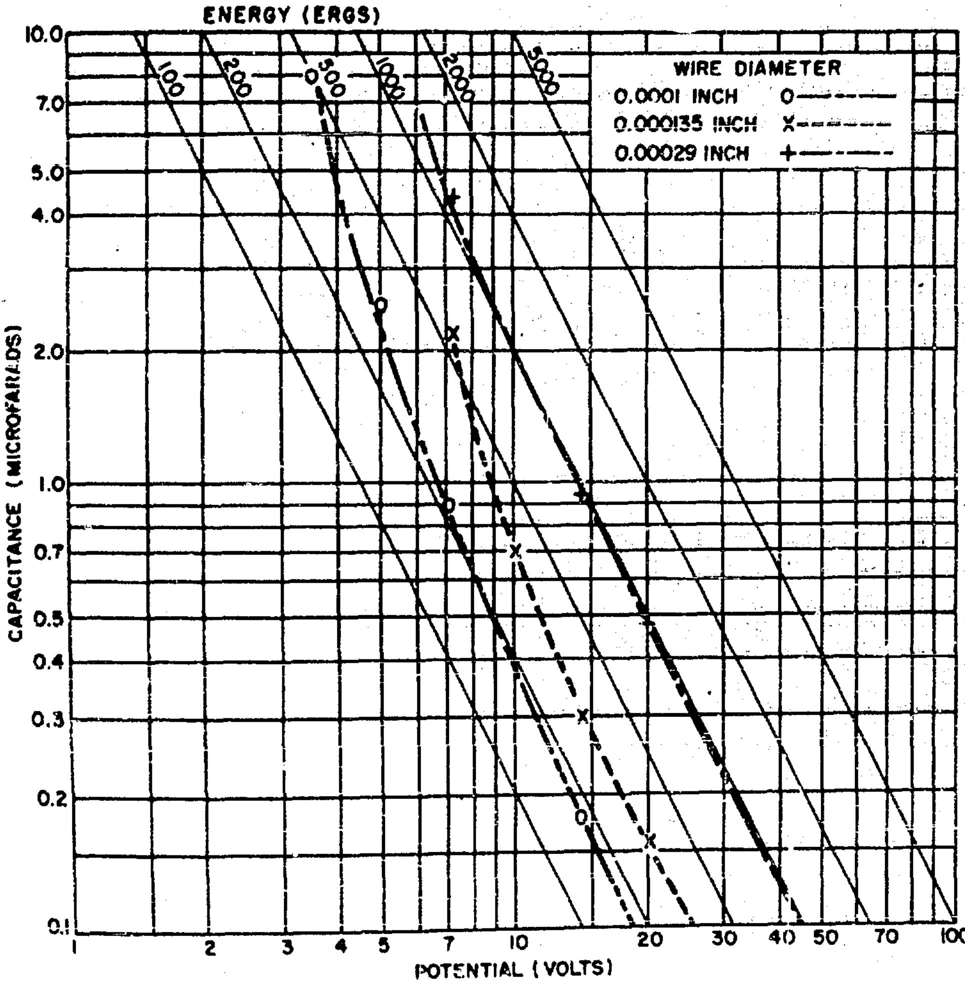

Figure 3–21. Capacitance Required for 50 Percent Firing vs. Potential for Electric Initiators with Tungsten Wire of Various Diameters. Flash Charge, Lead Styphnate.

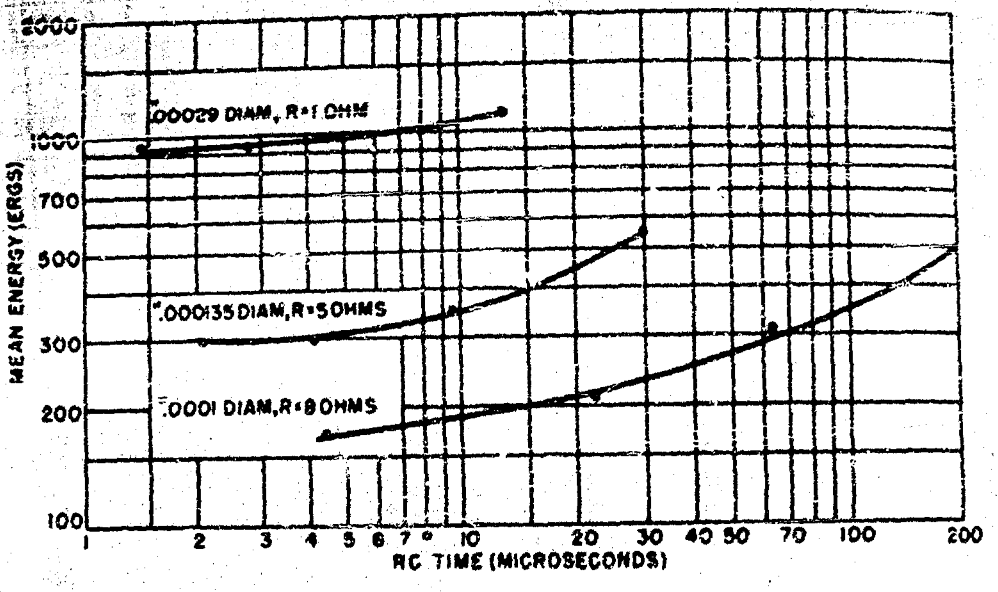

Figure 3–22. Effect of Time of Energy Input on the Firing Energy. Tungsten Wire 0.030 Inch Long with Lead Styphnate.

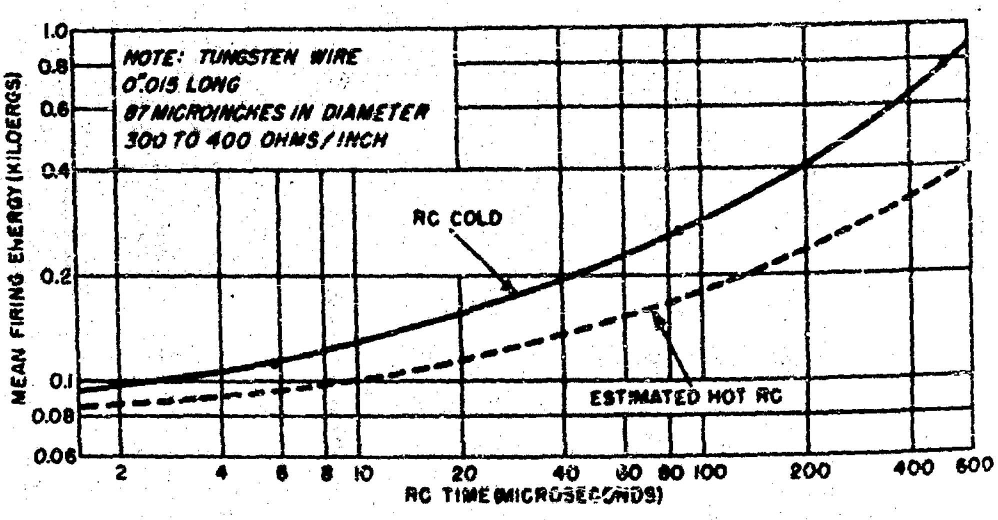

Figure 3–23. Effect of Time of Energy Input on Required Energy for 50 Percent Firing. Tungsten Wire with Lead Styphnate.

particularly where different bridge materials are used, it is often expedient to keep this relationship in mind.

Figure 3–24 is based on the same experimental data as figure 3–23, but the former is plotted to show that, as the RC time is made longer by increasing the capacitance at constant resistance, the required voltage for firing approaches a constant minimum value. In this instance, the minimum firing voltage appears to be between 1.0 and 1.3 volts.

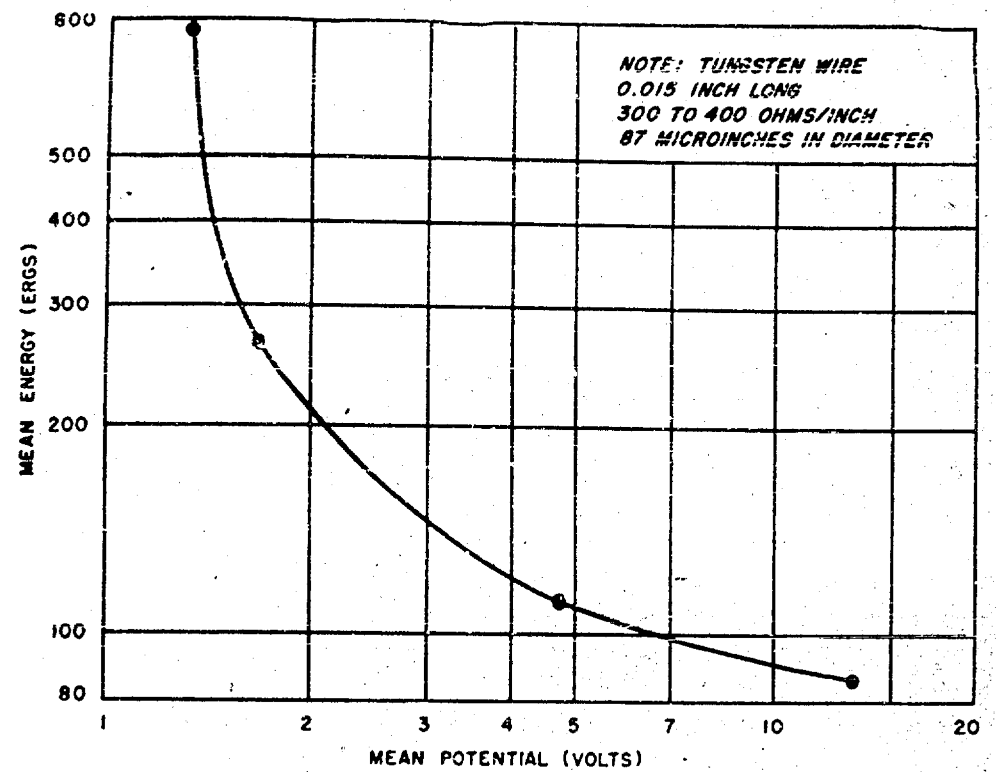

Figure 3–24. Effect of Potential on Required Energy for 50 Percent Firing. Tungsten Wire.

Figure 3–25 shows data similar to that of figure 3–23, but for electric fuze Primer Mk 112.

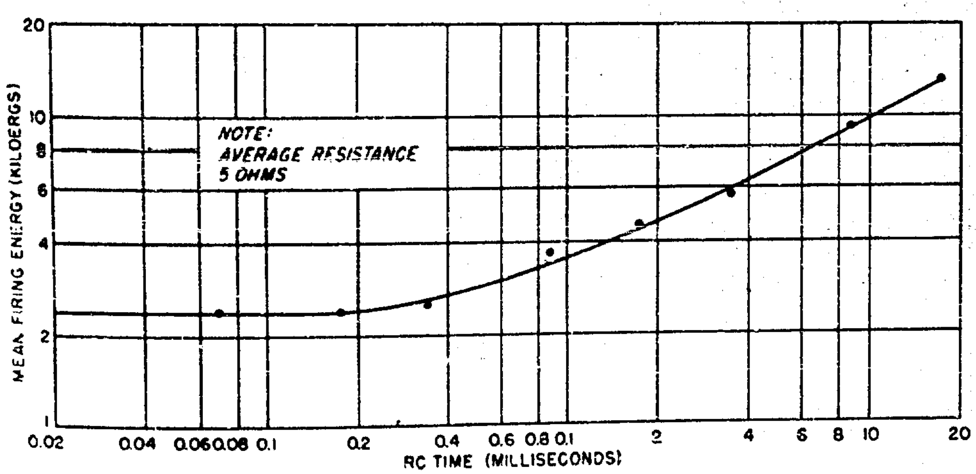

Figure 3–25. Effect of Time of Energy Input on Required Energy for 50 Percent Firing. Electric Fuze Primer Mk 112.

Inductive firing circuits. By adding a large enough inductance to the condenser discharge type circuit, the rate of energy input becomes independent of the capacitance and is governed by the factor 2L/R. It is possible to show by the use of such an inductive circuit that the considerations given in the previous section are valid and that the energy required for firing is truly a function of the rate of energy input.

This relationship is shown in figure 3-26, on which is plotted the ratio of the mean energy required for firing to the minimum mean energy requirement at very short input times vs. the input time for both inductive controlling and capacitive controlling circuits. It will be noted that the points for both types fall on the same curve, showing that the governing factor is the rate of energy input, not the individual circuit characteristics.

Constant current firing circuits. Complete data relating the constant current required to fire a primer to wire diameter, wire length, or explosive material have not as yet been gathered. In fact, the information is rather lean, and more work in this field is required. Figures 3-27, 3-28, and 3-29 show the effect of firing current on percent of primers firing for two types of spray-metal primers and for Primer Mk 112, respectively. In these tests, the constant current was started through a short directly across the primer bridge. Then, without interrupting the current flow, the short was removed and the current allowed to flow through the primer bridge for a period of at least 10 seconds if firing did not occur before this period. In many cases the current was allowed to flow longer, but if firing did not occur in 10 seconds or less, it did not occur at all even up to times of 1 minute in some instances.

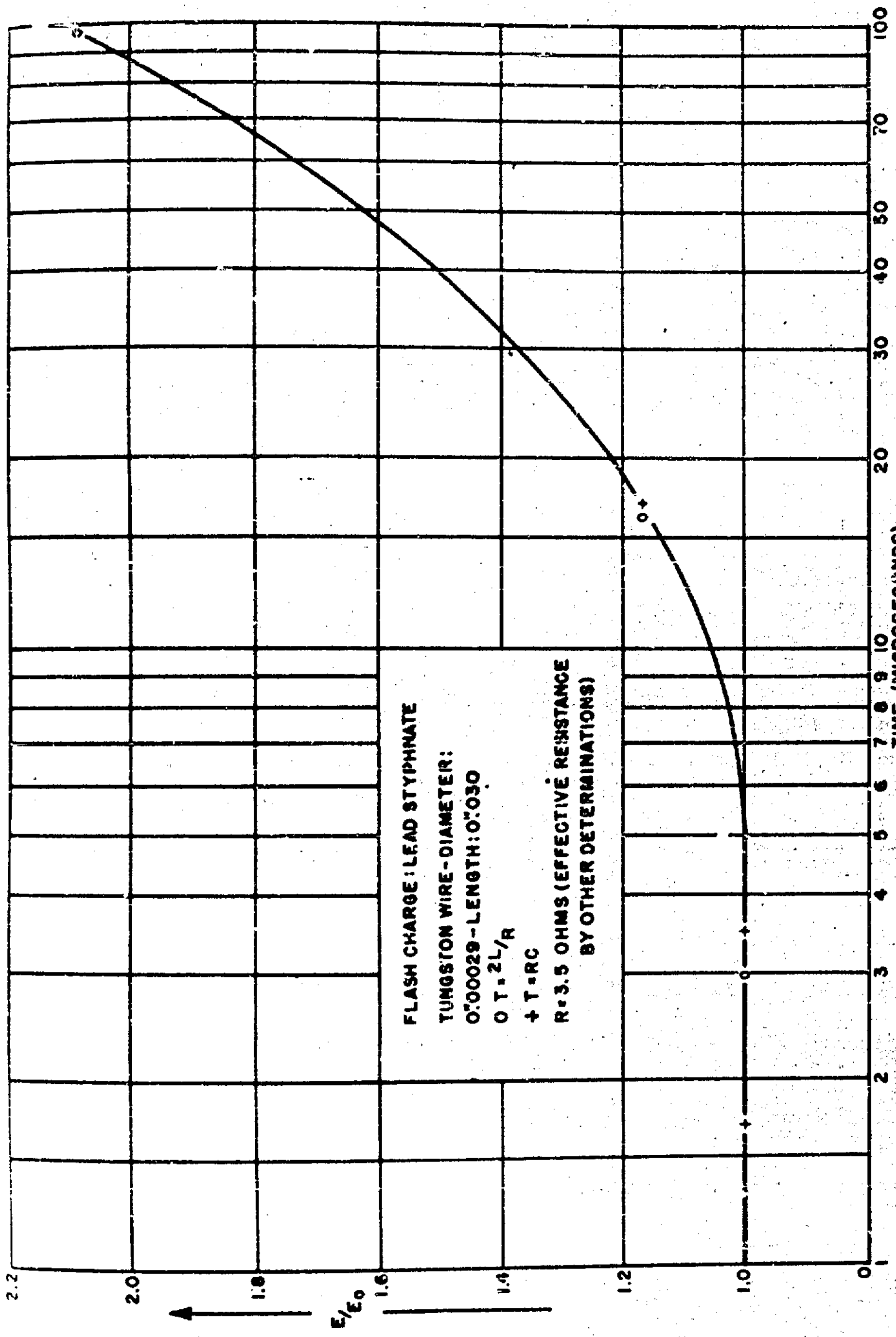

Figure 3-26. Energy Requirements vs. Pulse Decay Time. Energy Referred to Short Period Value To Eliminate Loading Variables, etc., Between Batches.

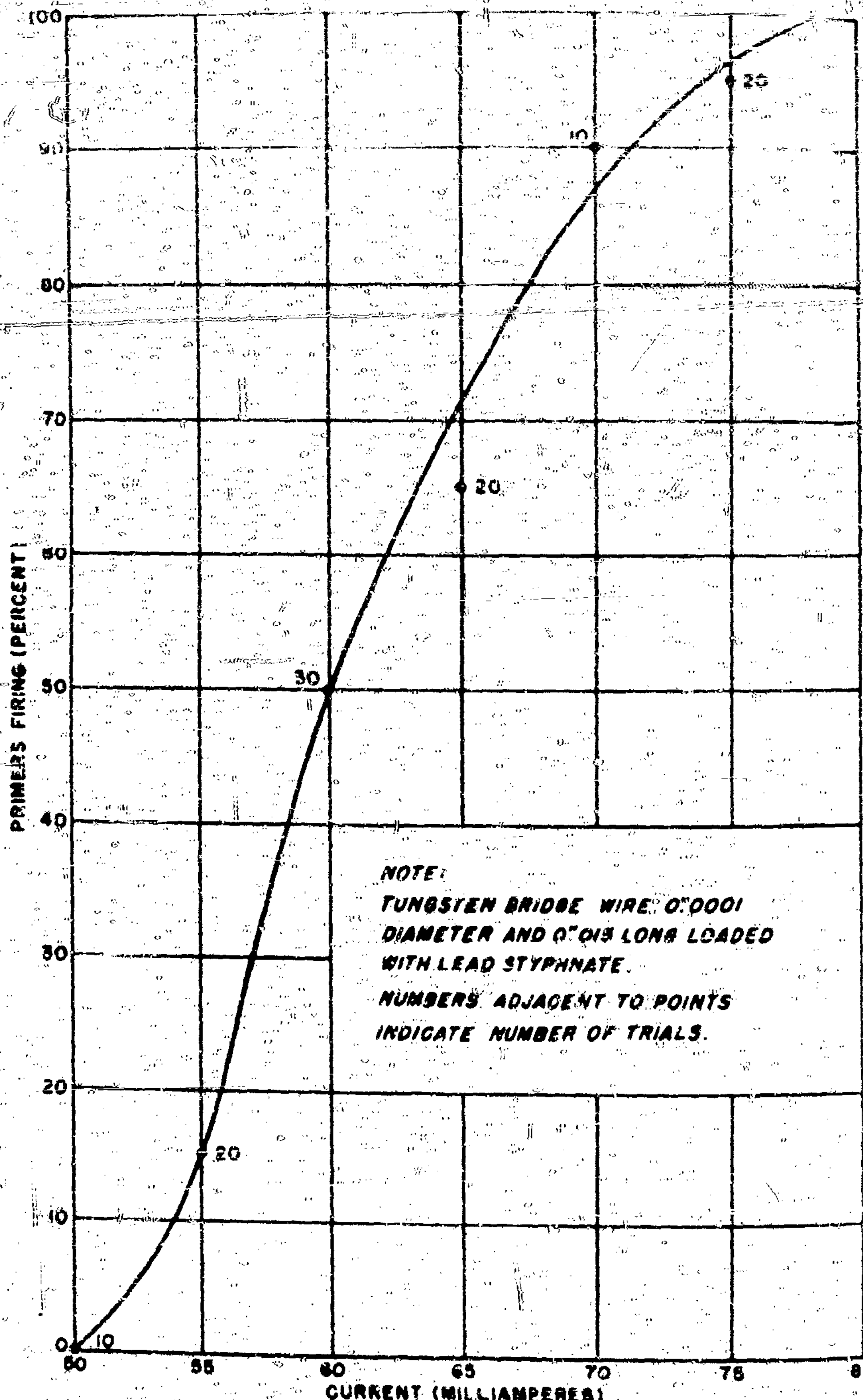

Figure 3-27. Percent of Primers Firing vs. Current Input, 0.0001 Inch Diameter Tungsten Wire With Lead Styphnate.

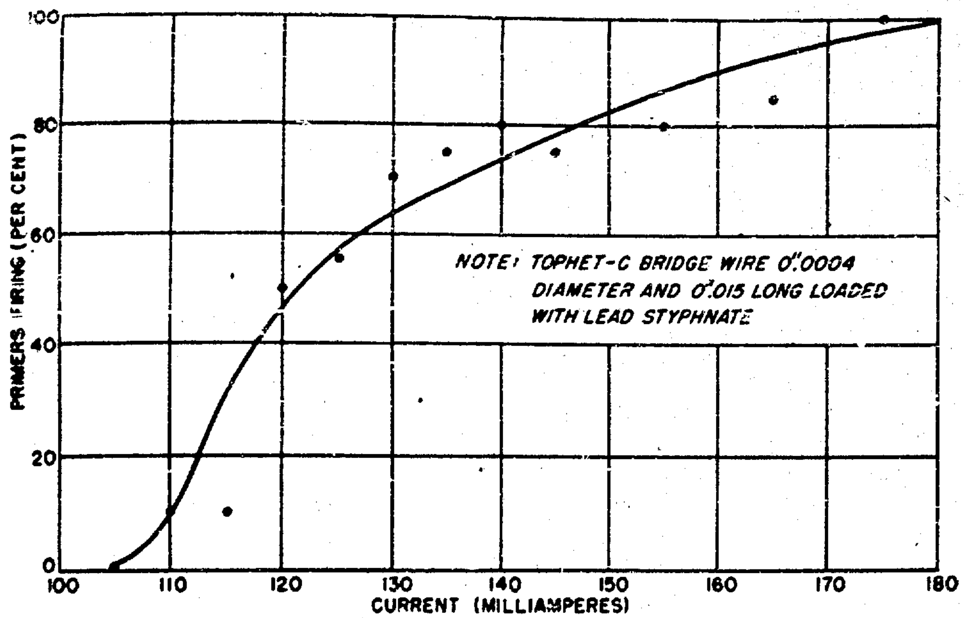

Figure 3–28. Percent of Primers Firing vs. Current Input. 0.0004 Inch Diameter Tophet-C Wire With Lead Styphnate.

The reason for starting the current through an auxiliary short is to eliminate inductive surges during the current starting period. It was found that these surges could give completely erroneous results if allowed to pass through the primer bridge. Some data have been obtained that show the effect of wire diameter and wire length on the required constant firing current necessary for spray metal primers with tungsten wire bridges and lead styphnate flash charges. The data are summarized in the form of the graph shown in figure 3–30.

This illustration shows that for tungsten wire with lead styphnate in the range tested, the constant current requirement at a fixed bridge length is proportional to the 3/2 power of the wire diameter. The displacement of the curves with change in wire length is explained on the basis of end effects, since the necessary constant current for firing, if end effect were not present, should be independent of wire length. This is true because by passing a fixed current through a wire of fixed resistance per unit length, the heating effect (or I^2R factor) per unit length is independent of the wire length. However, the heat dissipated by conduction through the wire ends is proportionately greater for the shorter wires. The ratio of the useful heat lost to the explosive to the heat lost through the wire ends is approximately proportional to the ratio 1/d, the wire length to the wire diameter.

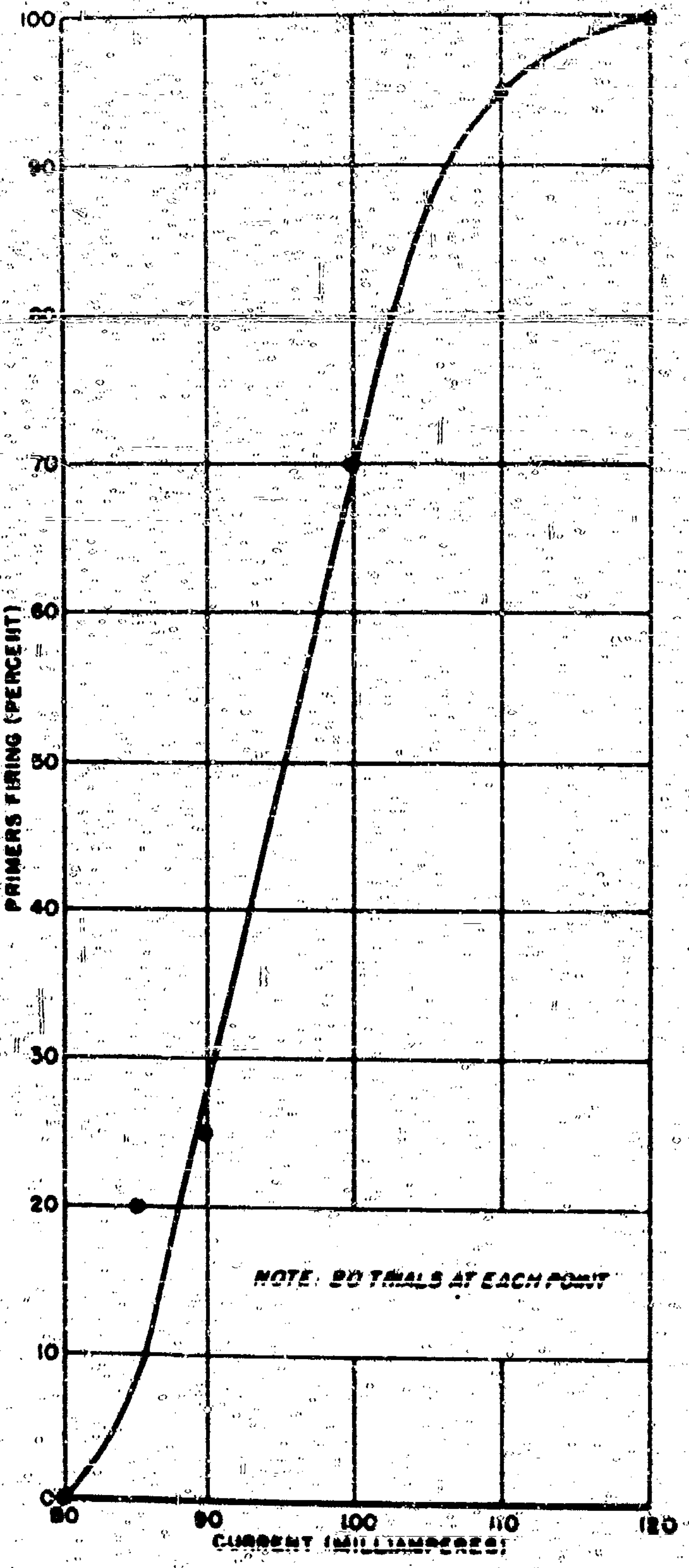

Figure 3-29. Percent of Primers Mk 112 Firing vs. Current Input.

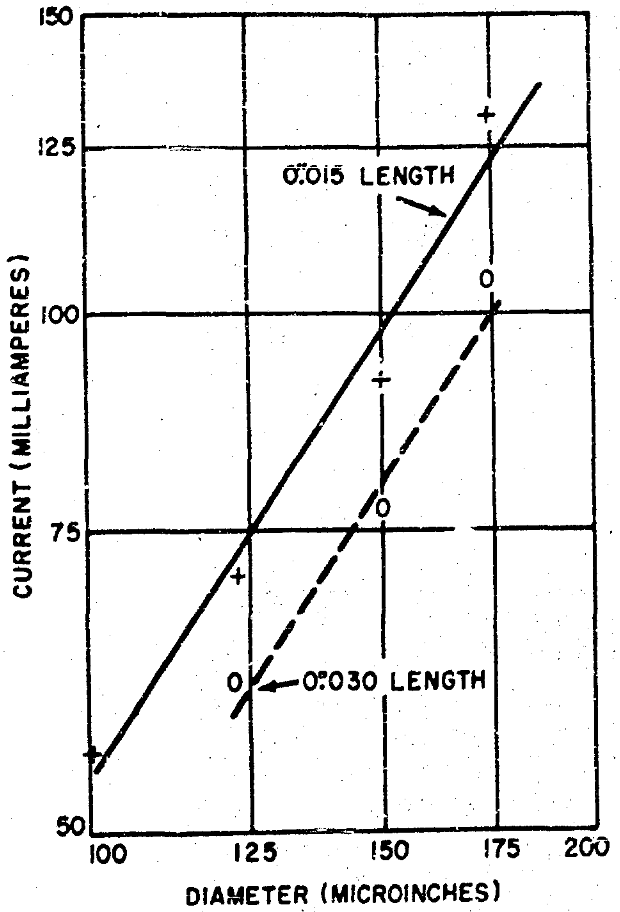

Figure 3-30. Variation of Firing Current with Wire Diameter. Spray Metal Primers Using Tungsten Wire with Lead Styphnate Flash Charge.

Effect of Different Explosives in Bridge-Wire Type Primer

As different primary explosives require different temperatures for ignition, it follows that different explosives will, with the same bridge system, require different firing energies. This fact is shown to some extent in figure 3-20, page 3-35. More data are given in table 3-12.

TABLE 3-12.—*Effect of Different Explosives on Firing Energy in Bridge-Wire Type Electric Primers. Tungsten Wire 0.030 Inch Long at 14-20 Volts*

Explosive	Energy (ergs)		Explosive	Energy (ergs)	
	0.0001 inch diameter	0.00029 inch diameter		0.0001 inch diameter	0.00029 inch diameter
$Pb(SCN)_2/KClO_3$-40/60	100	----------	LDNR	138	930
Tetracene	116	460	Mercury Fulminate	230	785
Cuprous Acetylide	123	750-850	DDNP/$KClO_3$-75/25	260	1050
Basic Lead Styphnate	125	700	Lead Azide	340	1340

Effect of Loading Pressure in Bridge-Wire Type Primer

This variable has been evaluated for lead styphnate with tungsten wire of 250–300 ohms/inch, 0.030 inch long, at 14–20 volts. The results are shown in figure 3–31.

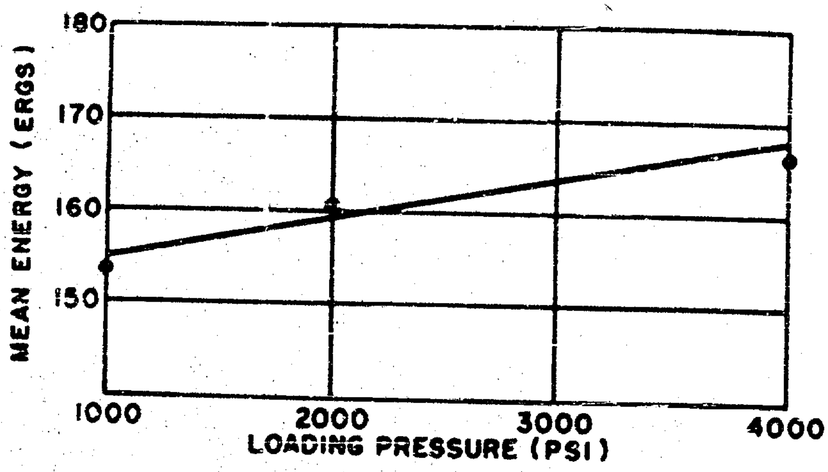

Figure 3–31. Effect of Loading Pressure on the Energy Required to Fire Spray Metal Primers.

Design of Input Characteristics for Bridge-Wire Type Primer

If a number of the foregoing factors are known, it is possible to estimate within about 20 percent what diameter and length of a given type wire with a given explosive is necessary to yield a primer of desired mean energy and resistance, the two most important factors which are ordinarily desired by the fuze designer.

Figures 3–32, 3–33, and 3–34, which are derived from figures 3–16, 3–17, 3–18, and 3–19, may be used to illustrate how a preliminary design is obtained. It is important first of all that the plots be determined in the desired RC or discharge time range. For a given RC range, enough experimental data are obtained to plot a curve as in figures 3–18 or 3–19, and from this plot a curve such as that shown in figure 3–32 is calculated by choosing the volume corresponding to the desired energy. Let us suppose that a 100 erg primer of 10 ohms resistance is desired and that figure 3–32 is available. An estimate good to within 20 percent of the required energy could be made for the necessary diameter and length by reading along the resistance axis to 10 ohms and taking the corresponding values of diameter and length. For the case given, these values are 81 microinches diameter and 0.023 inch length. By the use of a set of curves or a nomograph, which are easily prepared, it would be possible to interpolate for any value of energy, resistance, or diameter desired for a given discharge time.

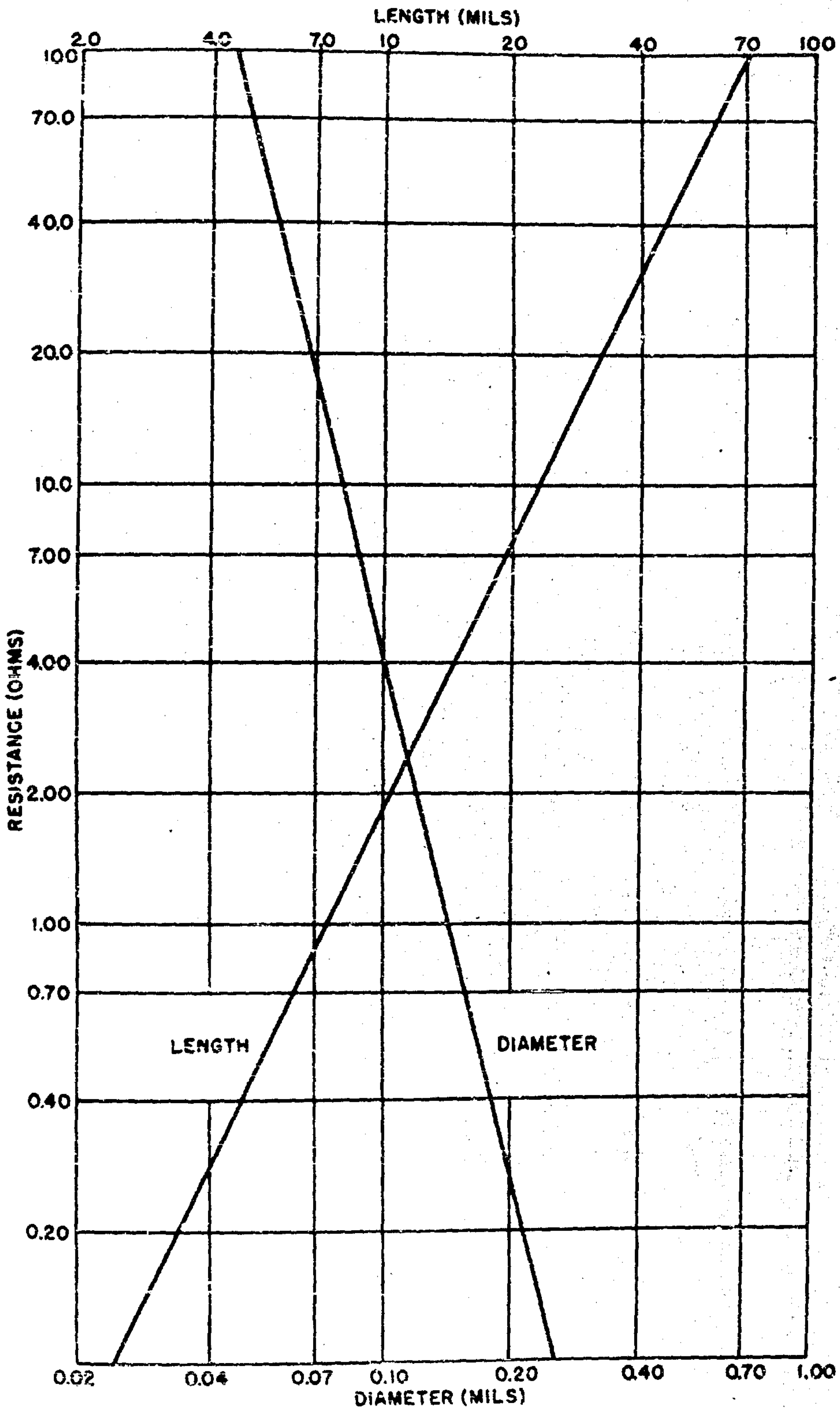

Figure 3-32. Length-Diameter-Resistance for 100-Erg Primers Using Tungsten Wire and Lead Styphnate.

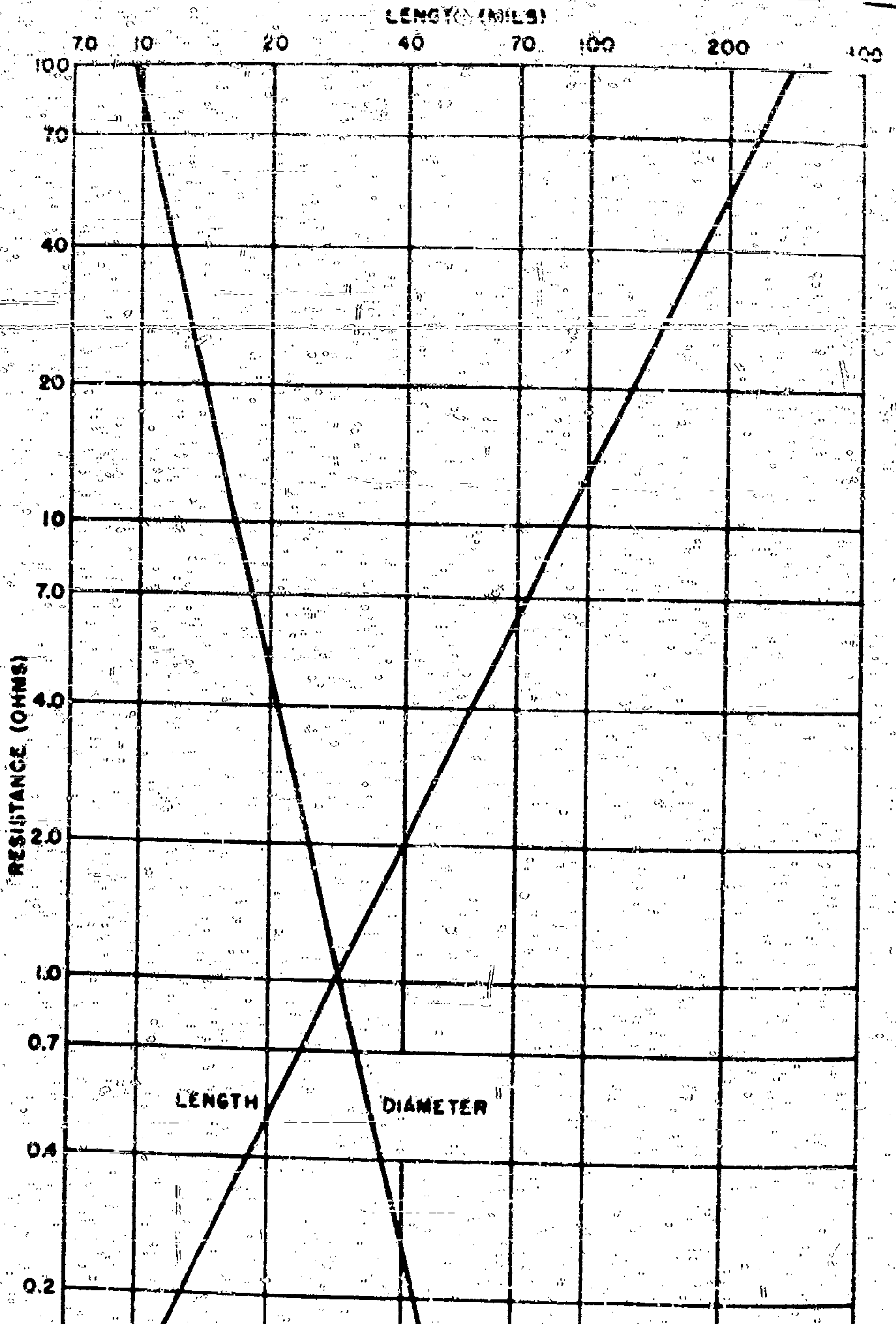

Figure 3-33. Length-Diameter-Resistance for 1,000-Erg Primers Using Tungsten Wire and Lead Styphnate.

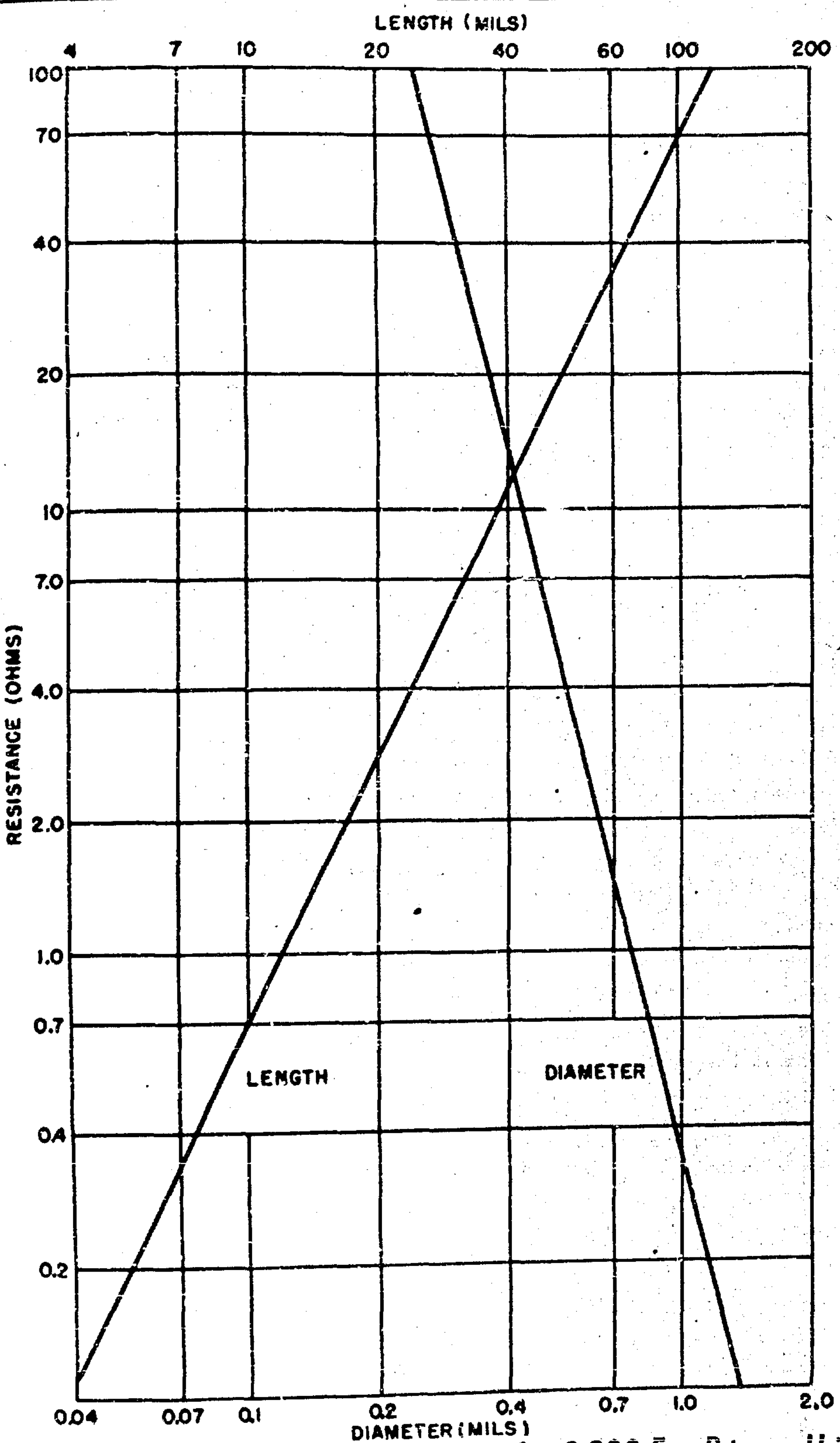

Figure 3–34. Length-Diameter-Resistance for 3,000-Erg Primers Using Tophet-C Wire and Lead Styphnate.

Input Characteristics of Carbon-Bridge Type Primer

General. This type of primer, a British innovation, has been under development in this country since World War II. The bridge, rather than being a wire is a conductive carbon film of small length (0.0012 inch maximum in Primer Mk 121). The bridge is usually formed on an insulating surface between two conductive surfaces by wetting the area to be bridged with an aqueous colloidal suspension of graphite. The thickness of the bridge, which remains after the evaporation of the water, may be regulated by varying the amount of graphite in suspension. This type of primer is characterized by high resistance (several thousand ohms), a negative temperature coefficient of resistivity, and high sensitivity. (Primers of less than 100 ergs firing energy can be made easily.)

This carbon bridge primer offers several advantages over the bridge wire type. Its high resistance makes it particularly suitable for circuits using a thyratron for triggering, as the thyratron efficiency in transferring the firing energy is so very much greater when working into loads of several thousand ohms compared with that obtained with the 2 to 10 ohm loads encountered in the conventional bridge-wire type low-energy primer. A second advantage is the ease of formation of the conductive bridge, eliminating the necessity of manufacturing and handling extremely small fragile wires. The major disadvantage of the carbon bridge primer is sensitivity to electrostatic discharges which tends to make it hazardous to handle.

The carbon bridge consists of a number of conductive paths rather than a single path as offered by a bridge wire. At the outset of current passage through the bridge, as in firing, the path of least resistance will get more current than adjacent paths and hence will be heated to a higher temperature. Since the carbon has a negative temperature coefficient of resistivity, the hotter path will have its resistance reduced still further and hence will receive proportionately a still greater amount of current. The repetition of this process tends to channel practically all the current into a single path in a very short time (microseconds). There is some evidence that during the course of firing by condenser discharge, the bridge resistance drops to about one-third its cold value, but this drop may vary somewhat depending on the rate of energy input.

A great deal of the data defining all the necessary variants for complete design of the carbon bridge primer have not as yet appeared. The bulk of the data existing can be found in references (11), (12), and (13). Some of the factors are discussed in following paragraphs.

Effect of film thickness. When the bridge is prepared, just enough carbon is deposited to give a satisfactory resistance. It is obvious

that heavier carbon deposits will necessitate more energy input for firing, as there is more carbon in any given path to be heated to the explosion temperature of the igniting explosive; complete data on this effect are not as yet available. Figure 3–35 shows this tendency rather clearly.

Effect of film length. Just as the film thickness necessitates more energy for firing, increasing the bridge length is known to have the same effect; however, where increasing the thickness of film for a given length reduces resistance, increasing the length for a given film thickness increases the bridge resistance. For this reason, one may design a primer, within certain limits, to obtain both a prefixed energy and a prefixed resistance by the expedient of choosing proper bridge length and bridge thickness. However, the exact variation of firing energy with bridge length has not been defined; until this is done, and until more is known about the effect of carbon concentration in the dag, systems of cut-and-try must be used to obtain the desired characteristics, where these vary from the standard Primer Mk 121.

Effect of rate of energy input. Besides bridge length and dag concentration, there is another factor by which the energy requirement can be partially controlled in condenser discharge type firing circuits. This is the rate of energy input. The discussion here coincides with that in the earlier discussion of Effect of Rate of Energy Input in Bridge-Wire Type Primers (page 3–36), with the exception that no actual data are on hand to demonstrate the supposedly larger effect on bridges of small film thickness, analogous to the greater effect experienced with the smaller bridge wires. Data have been obtained, however, for the variation of energy required with time of input (ref. (12)), and these curves have the same characteristics as those in figures 3–21 to 3–25 for bridge-wire type primers.

Output Characteristics

There is no doubt that the output characteristics of a primer depend greatly on its shape, the distribution of explosives material within it, the strength of the confining primer cup, the base charge explosive, and its loading pressure or confinement. The important considerations in designing for output are that the output be great enough to actuate the next element in the train but not so great that the fuze becomes unsafe. The matter of actual design is usually a cut-and-try method wherein the weight of base charge is varied and its effect on the functioning of the next element and on the safety of the fuze are determined. From these data, the proper weight of base charge is chosen; if this does not yield the desired result, a redesign of the primer cup is usually necessary.

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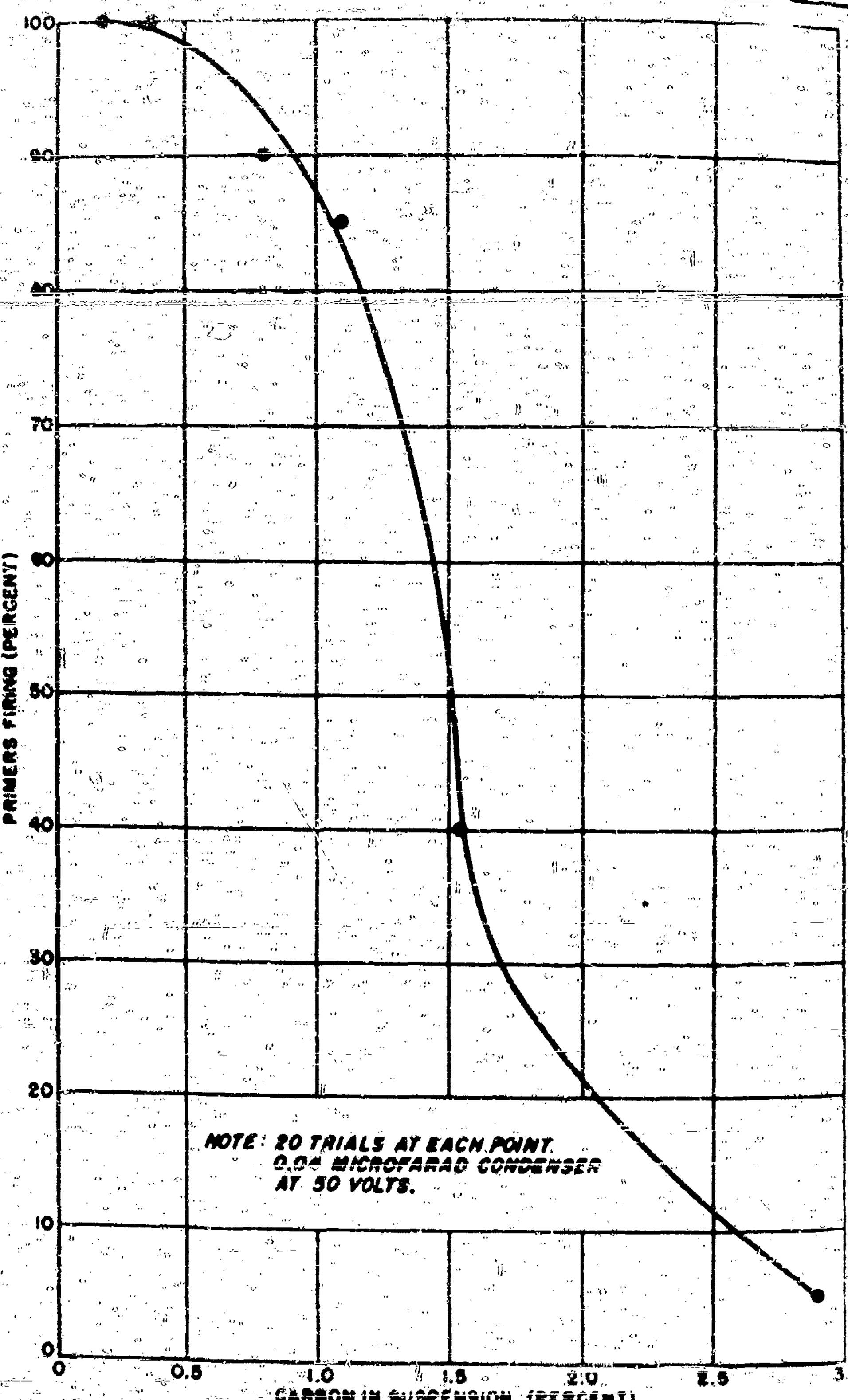

Figure 3-35. Effect of Dag Concentration on Firing of Carbon Bridge Primers.

It is possible, of course, to make measurements of brisance as in the sand bomb test and from these to evaluate some of the variables described in preceding topics. This method gives a qualitative answer as to how best to arrange the variables to obtain the desired effect. However, the final answer is affected by the surroundings of the primer in the fuze, and the exact effects produced by the surroundings is a complex function that has as yet defied quantitative solution. For comparison, table 3–13 shows the sand crushed by the various electric primers discussed.

TABLE 3–13.—*Sand Bomb Test of Various Electric Primers*

Primer	Weight of ignition charge (mg)	Weight of base charge (mg)	Sand crushed (mg)
Mk 112	60	60	5.3
Mk 121	60	60	5.3
Spray Metal	5	100	2.3

Section 4.—References

Parenthetical number preceded by the letter "S" are Naval Ordnance Laboratory file numbers.

(1) Picatinny Arsenal Technical Report, Serial No. 1475, **Effect of Variations in Shape of Firing Pin Points on Sensitivity of Detonators.** November 17, 1944. (S–5643).

(2) Arkansas Ordnance Plant Technical Problem No. 36, **Navy Mk 27 Fuze Firing Pin.** January 18, 1943.

(3) Arkansas Ordnance Plant Technical Report No. 79, **Firing Pin for Test of Mk 27 Detonators.** March 30, 1943.

(4) Arkansas Ordnance Plant Technical Report No. 80, **Effect of Firing Pin Point on Mk 46 Detonator Sensitivity.** March 31, 1944.

(5) NOLM 5659, **Mk 19 Sensitive Primers—Sensitivity Tests of.** July 1, 1944.

(6) NOLM 7914, **Optimum Loading Pressure for Mk 19 Sensitive Primer.** November 29, 1944.

(7) NOLM 9278, **Design and Surveillance of Copper Sealing Cups for Use in the Mk 101 Primer,** First Progress Report.

(8) Frankford Arsenal Report R–586, **Effect of Firing Pin Contour on Primer Sensitivity,** First Report, Project 3/276, by M. Stevens. (S–5862).

(9) Frankford Arsenal Report R–462, **Primer Sensitivity vs. Firing Pin Eccentricity,** First Report, Project 3/270, by M. R. Stevens and C. W. Churchman. (S–5977).

(10) NOLM 8696, **A Method for the Fabrication of Low Energy Electric Initiators.** August 16, 1946.
(11) Eastman Kodak Report NOD–EM 350, **Status Report on Carbon ("N") Sensitive Squib Cannon Primer.**
(12) Report, N. A. MacLeod to D. H. Sage, NOTS, Inyokern, Reg. No. 8684, 36. February 24, 1947.
(13) NAVORD 1006, **Study of Detonators Initiated by Low Energy Electrical Impulses,** by N. A. MacLeod. (S–18600).
(14) ARD Explosive Report 135/44, **Ignition of Explosive Substances by Hot Wires.** (S–6399).
(15) NOLM 10771, **Firing Characteristics of Electric Initiators Made by the Spraymetal Process.** March 30, 1950.
(16) British Report, 1.7 gr. "A" Mixture Detonators **Trials to Determine the Comparative Sensitivity When Fired by (a) Ball and Standing Striker (or needle), (b) Free Falling Striker.** (NOL Library No. S–26938; no other reference on report).
(17) Army Ordnance Drawings 73–8–250 and 74–2–76.
(18) NOLM 9399, **Surveillance Evaluation of Sealing Compounds for Navy Fuze Primer, Mk 101,** December 4, 1947.

Chapter 4

CHARACTERISTICS OF DETONATORS

The detonator is normally the element in the explosive train which effects the transition from deflagration to detonation. The detonator performs three distinct functions which may be performed by one, two, or three different explosive charges. These functions are (1) the initiation of deflagration, (2) the transformation of deflagration to detonation, and (3) the transfer of the detonating impulse to the next item in the train.

The deflagration may be initiated in a primary explosive or a priming mixture, sometimes called the upper charge, in the sensitive end of the detonator. The transition from deflagration to detonation is usually effected by an intermediate charge of lead azide, although mercury fulminate and diazodinitrophenol have also been used for this purpose. The transfer of detonation to the next item may be done by the lead azide, but in the case of the more powerful detonators a high explosive base charge such as PETN, Tetryl, or RDX performs this function.

Detonators are usually classified according to the method of initiation, as flash, stab, or electric detonators. These are discussed in the following sections.

Section 1: Flash Detonators

General Performance Characteristics

A flash detonator is designed to deliver a detonating impulse when acted upon by a heat impulse or a detonating impulse generated by a previous element.

Heat impulses for initiating flash type detonators may result from the flash from a delay element in delay type fuzes or the flash from a primer in instantaneous type fuzes.

When initiation results from the functioning of a previous detonator, the flash type detonator usually serves in the capacity of a relay where the gap over which the detonation must be transmitted is too great for the primary detonator to be effective.

Advantages. The sensitive initiating explosive in flash detonators makes them valuable for the development of a detonating impulse from a heat impulse emitted by a previous train component or for the boostering of a previously emitted detonating impulse.

Limitations. Lack of stab or percussion sensitivity makes flash detonators useful only where the initiation impulse is supplied by a previous explosive element.

Construction

General characteristics. The construction of flash type detonators is in line with general detonator construction, that is, each detonator consists of a metal capsule containing a charge of primary explosive or a charge of primary explosive plus a base charge of a booster type explosive.

Various types of closures are employed. The most common type is the disk closed end with the sidewall of the detonator cup crimped over an aluminum sealing disk. In another design, the initiating end of the detonator is closed by a paper disk held in place by an aluminum washer over which the sidewall of the detonator is crimped. In another variation, the closure of the initiating end of the detonator is the solid end of the detonator cup coined to a suitable thickness. The coined end is considered to be an advantageous type of construction from the standpoint of surveillance, but this advantage may not compensate for the manufacturing difficulties and the loss of sensitivity which this type of construction entails.

Suitable primary explosives. The acceptor explosive of all Navy flash initiated detonators is lead azide. Reference (1) indicates that all flash type detonators used by the Army contain lead azide as the acceptor explosive. Some Navy flash type detonators contain a tetryl base charge, while others are loaded completely with lead azide. Reference (1) indicates that all Army flash type detonators contain a tetryl base charge.

An analysis of the explosive components of detonators of foreign ammunition was made at Picatinny Arsenal and is reported in reference (2). This report mentions a variety of explosives used in flash type detonators. The findings are summarized in table 4-1.

Metals for components. Since both Army and Navy flash type detonators employ lead azide as an explosive ingredient, aluminum is the metal usually used for components.

Examples of Flash Type Detonators

The design of flash type detonators most commonly used follows that of Detonator Mk 37 Mod 0, shown in figure 4-1. Variations from the most commonly used design are shown by sketches of Detonators Mk 33 Mod 0 and Mk 45 Mod 0, also shown in figure 4-1.

Detonator Mk 37 Mod 0 is a compound detonator containing two increments of lead azide and one of tetryl. It is used in auxiliary detonating Fuzes Mk 44 and Mk 46 and is initiated by the detonation of a lead azide detonator in the nose fuze. Detonator Mk 37 initiates a tetryl lead.

TABLE 4-1.—*Explosive Charges Used in Foreign Flash Detonators*

Detonator upper (flash sensitive) charge composition	Detonator base charge	Ammunition	Origin
Black Powder	Mercury Fulminate	90-mm H. E. Shell	French.
Loose Mercury Fulminate	Pressed Mercury Fulminate.	81-mm H. E. High Capacity Mortar.	Italian.
Mercury Fulminate	Tetryl	Grenade	Japanese.
Lead Azide	Tetryl	25-mm H. E. Shell	Do.
Lead Azide	PETN	20-mm H. E. Shell	German.
Lead Azide (75 percent) PETN (25 percent)	PETN	Rifle Grenade Discharger	Japanese.
Lead Azide (77±8 percent) Lead Styphnate (23±8 percent)	PETN	80-mm Mortar	German.
Lead Azide (58±2 percent) Lead Styphnate (42±2 percent)	PETN	75-mm Howitzer	Do.
Lead Azide (80 percent) Lead Styphnate (20 percent)	PETN (94 percent) Wax (6 percent)	75-mm A. P. Capped Pak 40	German.
Lead Azide (60 percent) Lead Styphnate (30 percent) PETN (10 percent)	PETN	30-mm Bounding Type	Do.
Lead Azide (51.7 percent) Lead Styphnate (48.3 percent)	RDX	47-mm H. E. Grenade	Italian.
Lead Azide (76 percent) Lead Styphnate (24 percent)	RDX (96.5 percent) Wax (3.5 percent)	38-mm Capped	German.
Separate Charges of Lead Azide, Lead Styphnate.	PETN	20-mm A. P.	Italian.
Separate Charges of Lead Azide, Lead Styphnate.	Tetryl	76-mm H. E.	Russian.

Detonator Mk 33 contains only lead azide. The initiating end is covered with a paper disk and an aluminum washer, while the opposite end is covered with an aluminum disk retained by a partial crimp. When the detonator is assembled into the fuze plunger, sufficient pressure is applied to the detonator to complete the crimp. It is claimed that this type of assembly is conducive to a tighter fit in the detonator cavity in the fuze plunger. Detonator Mk 33 is initiated by the spit from a black powder delay element in a delay fuze, such as the Mk 19 base fuze, or by the spit of a percussion primer in an instantaneous fuze such as the Mk 28 base fuze. Detonator Mk 33 initiates a tetryl lead in both instantaneous and delay fuzes.

Detonator Mk 45 is a compound detonator containing both lead azide and tetryl. It differs from the other two detonators shown in figure 4-1 in that the sensitive end is a coined end. The opposite end is disk closed. Detonator Mk 45 is initiated by the fuze primer Mk 113 and, in turn, initiates a tetryl lead.

Input Characteristics

Adequate data are not available on the effect of design variables on the sensitivity of flash type detonators. The following variables would be expected to be important.

(a) Type of closure of the sensitive end, that is, crimped disk vs. coined end.

(b) Closure material used on the sensitive end, that is, metal vs. paper vs. organic sealant.

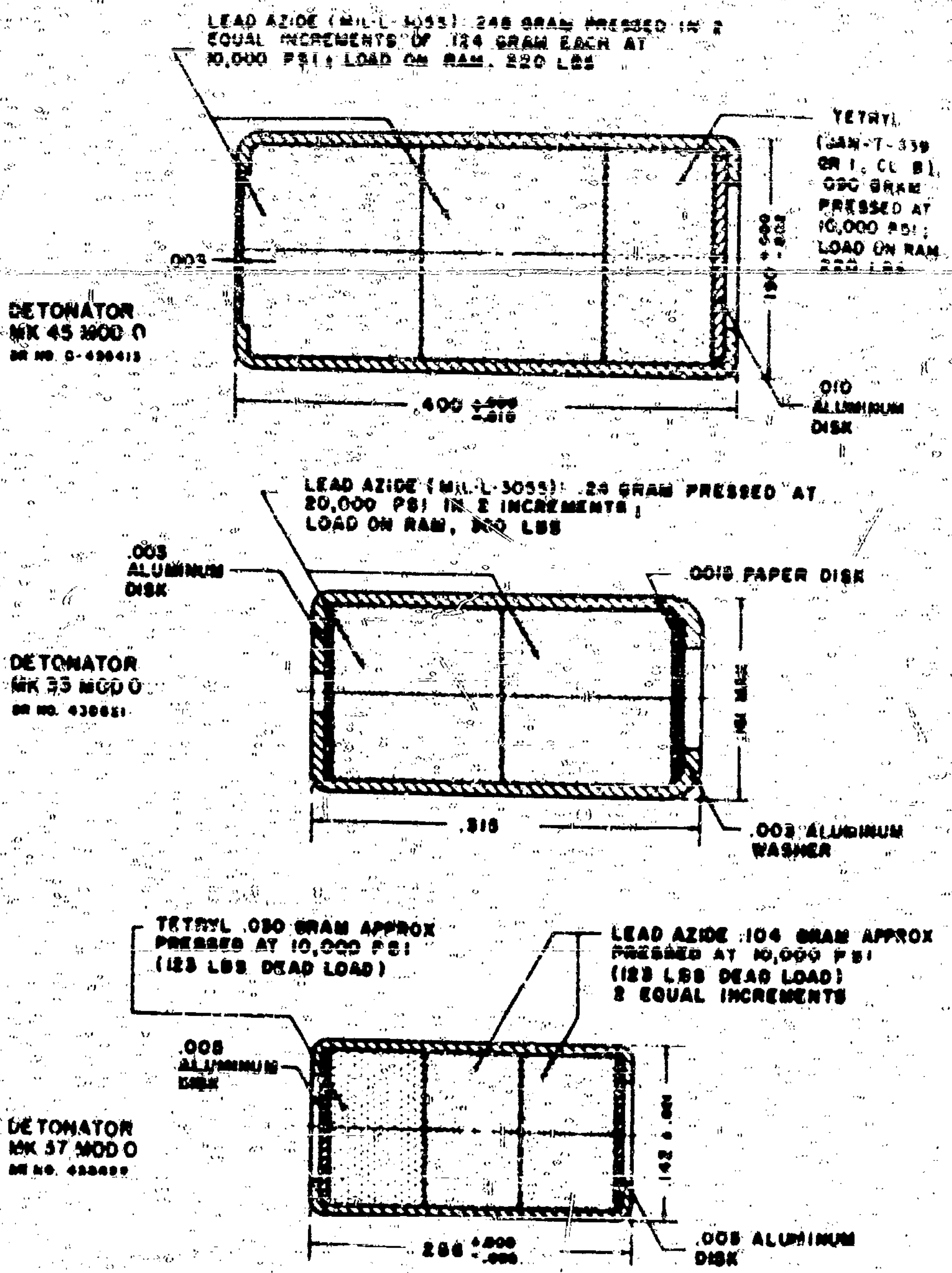

Figure 4-1. Examples of Flash Type Detonators.

(c) Type of explosive used in the sensitive end. The accumulation of data has been handicapped by the lack of an adequate test method for flash detonator sensitivity. Such an apparatus, the Flash Detonator Tester (Gas Blast), is being developed at the Naval Ordnance Laboratory. (See page 9–16.) The experimental instrument is described in reference (3); a revised "production" model is described in reference (4).

The "gas blast" detonator tester utilizes a sealed chamber containing approximately thirty cubic inches of a mixture of hydrogen and oxygen in a two to one volume ratio. The gas is ignited from the spark of a standard automotive spark plug. Suitable valves permit filling the chamber with the gas mixture to the desired pressure. The detonator is sealed into the bottom of the chamber with its flame sensitive end exposed to the burning gases. The chamber is evacuated prior to introducing the gases so that only hydrogen and oxygen are present. Some preliminary data have been obtained on the effect of two of the variables just named—type of closure and type of explosive.

Effect of type of closure on sensitivity. Using the experimental gas blast tester, sensitivity tests were carried out on Detonators Mk 45 Mod 0 and Mk 33 Mod 0. The data are tabulated in table 4–2.

TABLE 4–2.—*Effect of Type of Closure on Sensitivity of Detonators*

Detonator	Pressure of gas mixture (psi absolute)	Percent fired	Detonator	Pressure of gas mixture (psi absolute)	Percent fired
Mk 33, Mod 0	30	100	Mk 45, Mod 0	70	86
	20	81.8		65	55
	19	68.3		60	56
	18	56.1		55	63
	17	61.3		50	71
	16	46.3		45	66.6
	15	22.4		40	0
	14	1.6			

Both detonators contain lead azide on the sensitive end, as shown in figure 4–1. The difference in sensitivity of the two detonators is apparently due to differences in the construction of the sensitive end.

Effect of sensitive end explosive on sensitivity. Table 4–1 indicates that lead styphnate is often used in the upper (flash sensitive) charge composition of flash type detonators. Work of a preliminary nature indicates that the addition of normal lead styphnate to lead azide appreciably increases the flash sensitivity. In this work, lead styphnate-lead azide mixtures (each varying from 20 to 80 percent by percent increments) were loaded into aluminum Mk 102 type

primer cups and tested for sensitivity in the gas blast tester. Ten samples of primers containing each mixture were tested. With the mixture containing 20 percent lead styphnate, failures were experienced up to 30 pounds pressure; with 80 percent lead styphnate, no failures were experienced above 17 pounds pressure.

Output Characteristics

Specifications for the output of Army flash type detonators are given in reference (6). The sand test is used as the criterion of detonator output, and initiation is accomplished from either a black powder pellet or a lead azide charge resting on the detonator. The black powder or lead azide is initiated by a black powder fuse. Details of the sand test are given in reference (6). Specification requirements for Army flash type detonators are summarized in table 4–3. The total charge of sand in the sand bomb is 80 grams.

TABLE 4–3.—*Specification Requirements for Output of Army Flash Type Detonators*

Detonator assembly	Minimum amount of sand crushed (grams)	Detonator assembly	Minimum amount of sand crushed (grams)
M17	20	M31	45
M21	17	M36	34
M30	10		

The Navy has no standard test for the output of flash type detonators, although the expansion produced in a copper block of specified dimensions has been used for that purpose. (See page 9–32.) In the copper block test, the detonator is housed in a cylindrical copper block of a length equal to that of the detonator and outside diameter of 0.810±0.005 inch. The block contains an axial hole which accommodates the detonator snugly.

In general, the output can be controlled by the amount and brisance of the explosive or explosives used. For design purposes, especially where the available space is limited, it would be desirable to have information on the effect of the following variables on output.

(*a*) Relationship between the amount of various explosives and output as measured by available methods.

(*b*) The optimum ratio of amount of primary explosive to amount of base charge for various combinations of explosives and various sizes of compound detonators.

(*c*) Optimum length to diameter ratio for various explosive charges and various over-all volumes.

No information is available on (*b*) and (*c*) above. The available d

on the relationship between the amount of explosive and the output are presented in the following paragraphs.

Effect of amount of explosive on output as measured by the sand bomb. Sand bomb tests on various amounts of lead azide loaded into the body of underwater Detonator Mk 9 furnished a relationship between the amount of lead azide and the amount of sand crushed.

TABLE 4-4.—*Effect of Amount of Explosive on Output as Measured by Sand Bomb*

Grams lead azide	Grams sand crushed in 360-gram sand bomb (average of 5 values)
0.775	36
1.50	70
2.3	112
3.1	134

Underwater Detonator Mk 9 is initiated by two primers, Mk 112, but these are so highly confined that it can be assumed that they will not affect the amount of sand crushed.

Effect of amount of explosive on output as measured by the copper block test. In connection with the preparation of a specification for Detonator Mk 45, the output of which was evaluated by the copper block test, the question arose as to a correlation between copper block values and the initiating ability of the detonator. In the study of this problem, a series of Detonators Mk 45 was prepared in groups of 10 at each pressure from 250 psi to 10,000 psi, at varying increments of pressure. The expansion was determined for the copper blocks housing the detonators during explosion. The explosions of the detonators were initiated by fuze Primers Mk 113. Table 4-5 shows the quantities of explosive used and the copper block expansion for each loading pressure used.

TABLE 4-5.—*Effect of Amount of Explosive on Output as Measured by the Copper Block Test*

Loading pressure (psi)	Quantity of lead azide (grams)	Quantity of tetryl (grams)	Copper block expansion (inches)
[illegible]	0.160	0.069	0.079
[illegible]	.166	.069	.081
[illegible]	.182	.069	.083
[illegible]	.184	.069	.086
[illegible]	.208	.080	.092
[illegible]	.212	.080	.092
[illegible]	.236	.084	.098
[illegible]	.230	.085	.104
[illegible]	.248	.090	.112

Since the loading pressure, as such, would be expected to have little effect on output, it would seem that these data reflect the effect of amount of explosives. The data may be useful for design purpose where similar ratios of lead azide to tetryl are used.

Section 2.—Stab Detonators

General Performance Characteristics

The stab detonator usually functions as the initiating element of a fuze. This element, which is highly sensitive to the action of a stab firing pin, produces a detonation which can start the action of an explosive train by the initiation of a tetryl lead, a relay detonator, or a booster charge.

Advantages. The high sensitivity of stab-type detonators makes them suitable for use under conditions where mechanical initiating energy is low.

The stab detonator is initiated by a firing pin which is, in general, driven by one of three different means: (*a*) impact with the target, (*b*) spring action, or (*c*) gas pressure. This characteristic allows for the construction of a simple, compact, highly reliable firing mechanism.

Stab detonators are constructed to initiate tetryl leads, relay detonators, and in some cases booster charges.

Limitations. Stab detonators require mechanical energy for actuation and are, therefore, useful only where such energy is available.

The relatively high brisance of stab-type detonators as compared with primers makes them unsatisfactory for use as initiators of delays.

Construction

The stab detonator cup, or outer covering, is usually made from aluminum or aluminum base alloys for detonators containing an explosive charge of lead azide, whereas copper or copper base alloys are used for detonators containing mercury fulminate. The cup may have any one of several designs of closures. A few such designs are: two disk-closed ends; one disk-closed end, one coined end; one coined end, one open end; one disk-closed end, one open end.

The length of stab detonators now in use by the Army and Navy varies from 0.250 inch to 0.750 inch, and the external diameter varies from 0.110 inch to 0.300 inch.

The wall thickness of the detonator cups varies from 0.005 inch to 0.025 inch.

The disk thickness on the sensitive end of stab detonators varies from 0.001 inch to 0.005 inch.

The closing disk thickness on the insensitive end of stab detonators varies from 0.005 inch to 0.020 inch.

Suitable explosive components. Stab detonators contain explosive charges which usually consist of a priming mixture, a primary explosive, and a high explosive or base charge. However, in some cases the priming mixture and/or the high explosive may be omitted.

The priming mixtures used in stab detonators usually consist of a primary explosive, an oxidizing agent, a fuel, and frequently a sensitizing agent.

Priming mixtures now in use in both Army and Navy stab detonators are listed in table 2–3 (page 2–10).

Either mercury fulminate or lead azide is used as the primary explosive in stab-type detonators, while tetryl is commonly used as the high explosive.

Metals for components. Army and Navy detonator cups and disks are constructed of aluminum, copper, and gilding metal.

The metal should be compatible with the explosives with which it comes in contact. Lead azide reacts with copper to form cuprous azide, which is extremely sensitive. On the other hand, mercury fulminate and lead sulfocyanate react with aluminum to form less sensitive compounds.

Army and Navy procedure is to load mixtures containing mercury fulminate into copper or copper alloy components, while mixtures containing lead azide are loaded into aluminum or aluminum alloy components. The Army loads a mixture containing lead sulfocyanate and lead azide into gilding metal components that have been coated on the inside with shellac to separate explosives and metals which tend to react.

Examples of Stab-Type Detonators

Navy Detonators Mk 26 Mod 0 and Mk 28 Mod 0 represent two general types of stab detonators, and are illustrated in figure 4–2.

Detonator Mk 26 Mod 0, used in nose Fuzes Mk 135 and Mk 142, is initiated by a stab firing pin driven by spring action. The function of the detonator is to initiate a tetryl lead-in. This detonator is disk-closed at both ends and has an aluminum cup and closing disks.

Detonator Mk 28 Mod 0, used in auxiliary detonating Fuzes Mk 43, Mk 54, and Mk 55, is initiated by a stab firing pin actuated by gas pressure. This detonator functions as the initiator of a tetryl lead-in.

The Mk 28 Mod 0 is an open end detonator. The aluminum detonator cup has one solid end which is coined thin at the center to increase sensitivity to stab action. After loading, the exposed tetryl

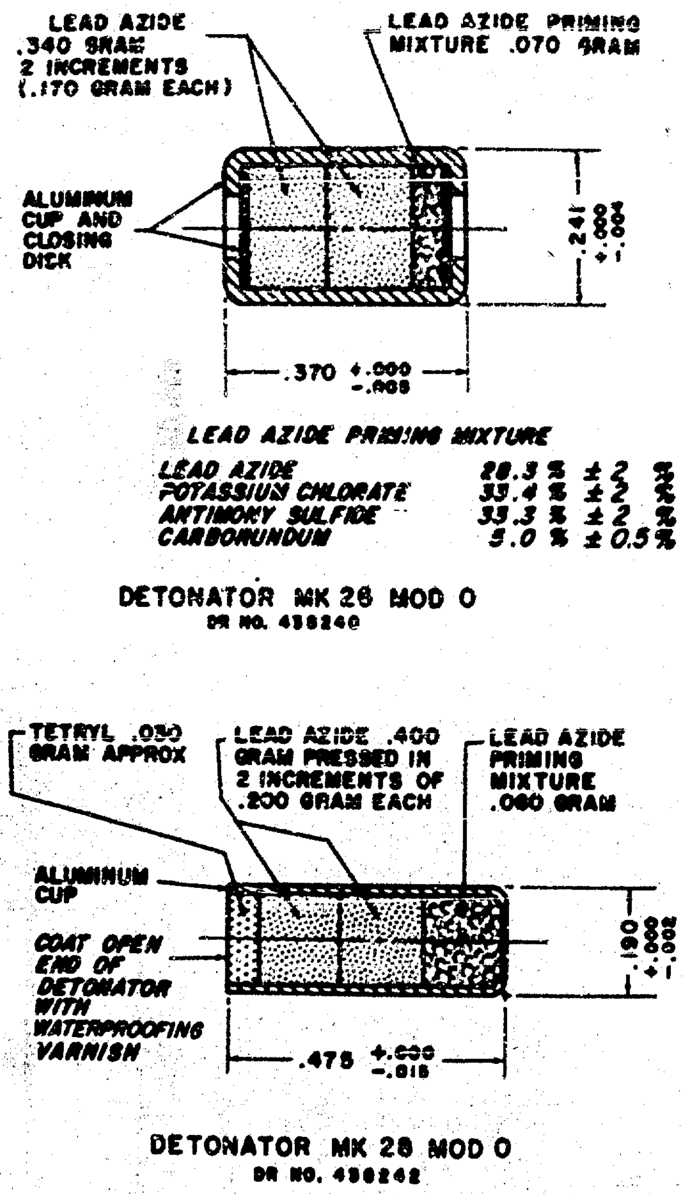

Figure 4–2. Two General Types of Stab Detonators.

at the open end of the detonator is sealed with a coating of water proofing varnish.

Input Characteristics

Effect of mechanical details. Details on optimum firing pin con- struction, relation of disk thickness to sensitivity, and effect of firing pin velocity on input requirements are identical with those for stab- type primers and are discussed in chapter 3 (pages 3–3 to 3–7).

Effect of loading pressure on input requirements. Tests wer undertaken to determine the optimum loading pressure for lea

azide priming mixture. (See table 2-3, page 2-10). Mk 28 detonator cups, which are of the coined-end type, were loaded with lead azide priming mixture and a lead azide primary charge. Seven groups of fifty detonators each were made up at 5000 psi intervals from 10,000 to 40,000 psi inclusive. A Bruceton sensitivity test was run on each group of detonators.

The sensitivity test results shown in the following table indicate increasing sensitivity and uniformity with increasing pressure to a maximum at 25,000 to 30,000 psi, with a subsequent leveling off at approximately the maximum value of each.

Loading pressure (psi)	Height of 50 percent functioning (inches)	Standard deviation (inches)
10,000	5.58	3.80
15,000	5.33	2.64
20,000	4.82	1.17
25,000	3.27	.95
30,000	2.92	1.07
35,000	3.04	.93
40,000	3.08	1.10

These results have been confirmed by more recent tests in which the NOL No. 130 Priming Mixture and lead azide priming mixture (see table 2-3, page 2-10, for compositions) were loaded at varying pressures in Mk 18, Mk 44, and Mk 28 type detonators (ref. (5)). The results are presented in table 4-6 and shown graphically in figures 4-3 and 4-4. These data differ from the earlier results in that the sensitivity does not level off at 30,000 psi, but keeps increasing up to 50,000 psi, which is the highest pressure tested.

This effect of increasing sensitivity and uniformity with increasing loading pressure is not shown by all stab-type priming mixtures. (See

TABLE 4-6.—*Variation of Sensitivity With Loading Pressure for Stab-Type Priming Mixtures*

Loading pressure (psi) in thousands	NOL No. 130 priming mixture loaded into detonator						Lead azide priming mixture loaded into detonator			
	Mk 18 (0.093 inch I. D.)		Mk 44 (0.140 inch I. D.)		Mk 28 (0.16 inch I. D.)		Mk 18 (0.093 inch I. D.)		Mk 28 (0.168 inch I. D.)	
	$\bar{X}$[1]	S[2]	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
10	1.80	0.52	1.04	0.23	2.46	0.29	4.81	3.44	4.97	1.40
20	1.42	.21	.99	.43	1.97	.84	3.10	2.81	4.04	.93
40	1.13	.33	.78	.17	1.72	.38	2.47	1.71	3.19	1.07
50	.98	.45	.56	.11	1.40	.29	2.01	1.71	[3] 3.01	1.41

[1] 50 percent firing height, inches, Test Set Mk 136, 2-ounce ball.
[2] Standard deviation in inches.
[3] No explosions experienced during pressing.

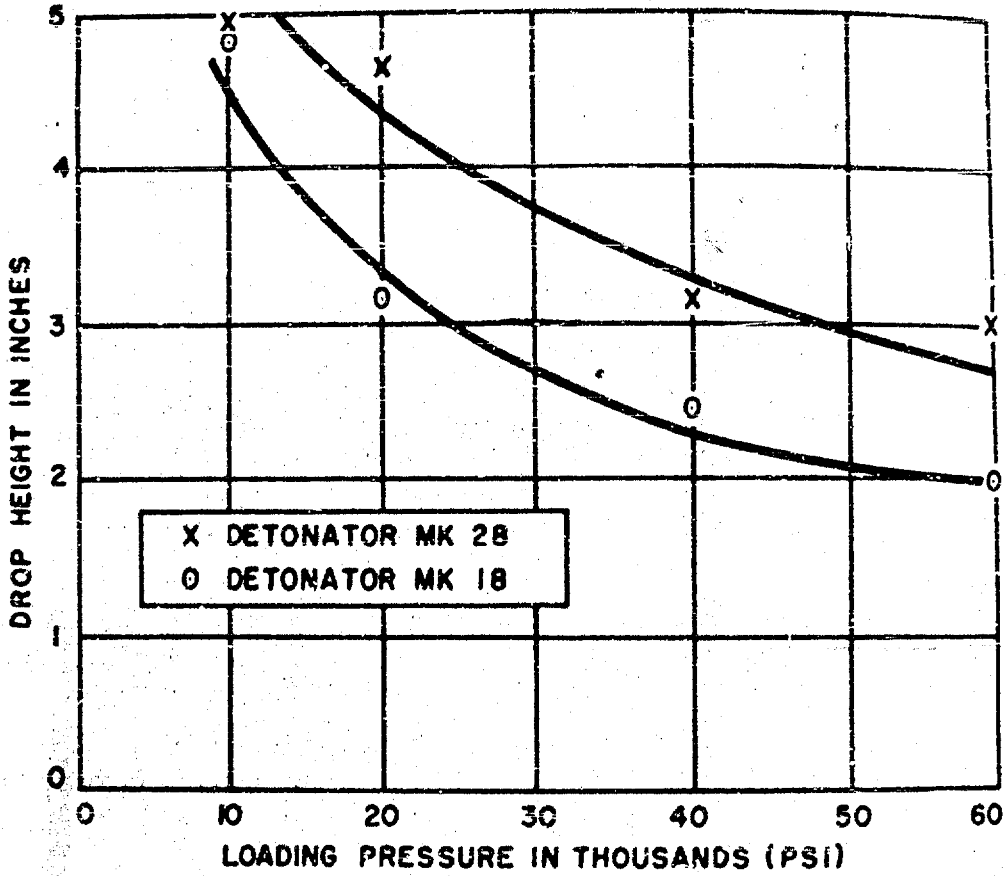

Figure 4–3. Effect of Loading Pressure on the Sensitivity of Lead Azide Priming Mixture, Test Set Mk 136, 2-Ounce Ball.

chap. 3, Stab Primers, Effect of loading pressure on input requirements (page 3–7). In those cases where the effect can be used, it offers an excellent opportunity for increasing the sensitivity and improving the quality of stab-type detonators and primers.

Output Characteristics

Effect of amount of base charge on output. A test was conducted in which Detonators Mk 28 containing a lead azide priming mixture (0.060 gram) and a lead azide primary charge were loaded with varying base charge weights of tetryl, PETN, and RDX.

These detonators were fired by a Bruceton test procedure. (See page 9–29). Measurements were made of the diameters of holes

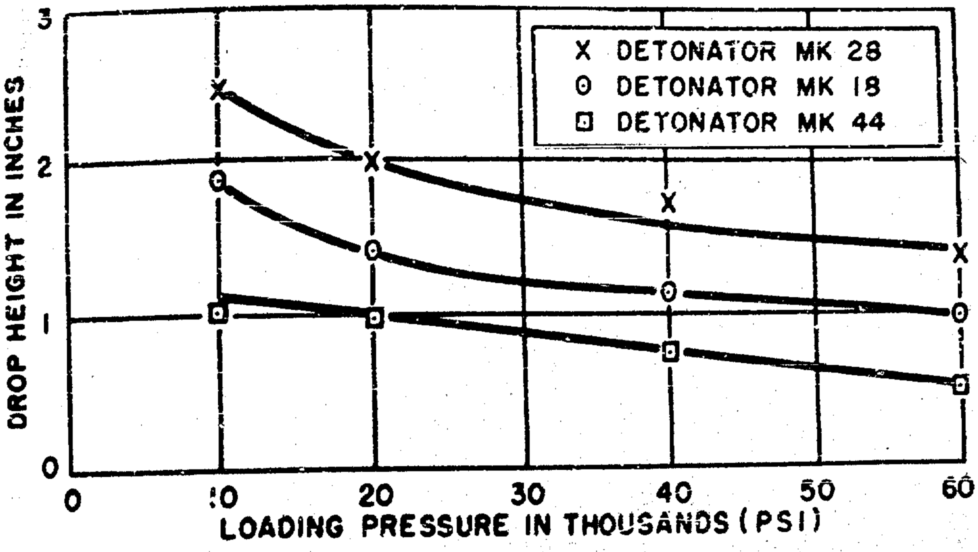

Figure 4–4. Effect of Loading Pressure on the Sensitivity of NOL No. 130 Priming Mixture, Test Set Mk 136, 2-Ounce Ball.

produced in lead disks by the explosion of these detonators. The results were as follows:

Explosive	Loading pressure (psi)	Base charge weight (grams)	Diameter of hole in lead disks (inches)	Standard deviation of hole diameters (inches)
Tetryl	10,000	0.030	0.239	0.0356
PETN	10,000	.030	.279	.0176
RDX	10,000	.030	293	.0077
Tetryl	10,000	.060	.267	.0372
PETN	10,000	.060	295	.0059
RDX	10,000	.060	.288	.0075
Tetryl	10,000	.090	.276	.0141
PETN	10,000	.090	.303	.0064
RDX	10,000	.090	.298	.0047

Detonators containing either RDX or PETN as the base charge appear to be considerably more powerful than those having a tetryl base charge.

The standard deviation of the lead disk hole diameters generally decreases with increasing base charge weight. RDX at all base charge weights has smeller standard deviations of lead disk measurements than either tetryl or PETN. This fact indicates more uniform explosions.

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Effect of input energy on output. A Frankford rundown sensitivity test (page 9–30) was conducted on one thousand production-loaded Detonators Mk 43. Measurements were made of the average diameters of the holes blown in the supporting lead disks by the detonator initiated at various drop heights. The results are shown in the following table:

Drop height (inches)	Average hole diameter in lead disk (inches)
2	0.211
3	.201
4	.206
5	.213
6	.202
7	.190
8	.210
9	.219
10	.230
11	.212
12	.233
13	.227

The data indicate that the input energy has no marked effect on output.

Section 3.—Electric Detonators

General Performance Characteristics

Instantaneous electric detonators are considered in this section. Electric delay detonators are included in chapter 5.

Electric detonators are used in Naval mine and torpedo firing mechanisms and to a limited extent in Army fuzes. They have not been employed in service Navy fuzes. Their limited use at present is chiefly due to the fact that, compared with fuze trains employing electric primers, those that utilize electric detonators require more space plus a somewhat more cumbersome mechanism to effect comparable safety. However, it should be realized that the field of electric fuze design is relatively new and that these handicaps may be overcome as the art progresses. Factors affecting the use of electric fuze detonators will be discussed more fully in the section under limitations.

Electric detonators, like electric primers, may be made to fire from suitable sources of electrical energy such as generators, batteries, or charged condensers; they may thus be made to fire from an electric pulse supplied by energy stored within the fuze firing circuit or by an electric pulse generated within the fuze system prior to or at impact.

The electric detonator is ordinarily used to actuate a booster or booster lead (normally tetryl).

In the discussions that follow, references are made frequently to section 3 of chapter 3, which deals with electric primers. It will be to the reader's advantage to be familiar with at least those portions of the preceding chapter which deals with input design, as the problem of designing for input characteristics is identical for both primers and detonators.

Advantages. Electric detonators, by virtue of their employment of electric initiation, possess a number of advantages over other varieties of detonators. Since these advantages are covered fully in section 3 of chapter 3, they are re-stated here only briefly:

(*a*) Electric detonators may be built to require less energy for initiation than do stab types.

(*b*) Features of selectivity or discrimination may be built around electric detonators.

(*c*) Simultaneous action may be started at points remote from the firing source.

(*d*) For certain applications, increased safety is realized over that of stab or flash type detonators.

(*e*) The input characteristics of electric detonators may be easily evaluated in the laboratory. Some of the characteristics may be determined by non-destructive testing.

In addition to these advantages over other detonator types, the electric detonator possesses an advanatage over the electric primer in that no flash detonator is required to be used with it. Hence the explosive train from electrical initiation to lead-in is loaded in a single unit. This eliminates the gap usually present between primer and flash detonator, which is one of the points at which an explosive train may fail.

Limitations and disadvantages. The disadvantages and limitations of electric primers are covered in section 3 of chapter 3. Many of these limitations are also inherent in electric detonators; namely,

(*a*) More involved construction than stab or flash detonators.

(*b*) The fuze employing them must carry along an energy supply or generator.

(*c*) The fuze must contain suitable electric firing circuits, which are usually more complex than the firing pin or flash actuating arrangements required with other detonator types.

(*d*) Special techniques are necessary for producing and handling fine bridge wires or for manufacturing the reproducible carbon bridges required for the low-energy detonators.

The electric detonator has come into only limited service use in electric fuzes because of these disadvantages and for several other reasons. It is the opinion of many fuze designers that from the

standpoint of safety and efficiency of space utilization, it is easier to effect a good design by using the primer-flash detonator combination.

For reasons of safety, it is normally considered desirable to provide one or more interruptions in the fuze train of an unarmed fuze. In the case of a primer-flash detonator combination, this may be effected by placing the detonator in a shutter which is turned out of alignment with both the primer and lead-in when the fuze is unarmed. On arming, the shutter is actuated and moves the item into alignment. Electric detonators, being larger and requiring electrical connections, do not lend themselves readily to this type of arming device.

Another argument advanced by the fuze designer is that some of the newer fuzes have two or more initiating elements incorporating delays of varying lengths. The fuze firing circuit is designed to initiate the element having the delay most appropriate for the target. If primers are used, it is relatively easy to fire through from any of the series of primers to a single shutter-mounted flash detonator even though all the primers cannot be perfectly aligned with the detonator. On the other hand, if detonators were used, it would be difficult to initiate a comparatively insensitive lead-in when alignment is poor. The latter arrangement would also involve a difficult safety problem.

Construction

General. The instantaneous electric detonator is ordinarily composed of an ignition element, an intermediate charge of primary explosive, and a base charge assembled within a single cup. This combination is not rigid; in some instances there are more than three charges, and in others no intermediate charge of primary explosive is necessary. The ignition element consists of a set of wire leads molded into a plug, a bridge-wire or conductive coating connected between these leads, and a sensitive explosive surrounding this bridge. The intermediate charge usually consists of a primary explosive of high brisance, such as DDNP/$KClO_3$ 75/25, or of lead azide. The base charge is a high explosive with suitable sensitivity and high output such as PETN or RDX.

Suitable explosives for the ignition element. The ignition element must contain about the bridge a highly sensitive explosive. The compositions that have found the greatest use to date have been lead styphnate and XC-9. The latter is a combination of diazodinitrophenol 75 percent with potassium chlorate 25 percent milled in a 2.4 percent solution of nitrostarch in butyl acetate. There are a variety of other explosives that could serve the purpose. Data on their sensitivities to ignition by various diameter wires are given in figure 3-20 (page 3-35).

In Detonator Mk 57, the bridge-wire only is coated with a thin layer of lead styphnate to get high sensitivity, while the rest of the ignition element contains lead azide to obtain high brisance. Such combinations make it possible to initiate the base charge (PETN) directly from the ignition element, thus eliminating the intermediate charge and reducing the size of the detonator.

Intermediate charge materials. These are sensitive and brisant primary explosives capable of being easily initiated by the ignition element and having fairly high output. Undiluted DDNP as well as mixtures of DDNP with potassium chlorate have been used. Lead azide has been used to some extent by the Army but has not found too much use in Navy electric detonators because of its incompatability with many metals and with some explosives.

Base charge explosives. These are comparatively sensitive high explosives that may be brought to full detonation in fairly short lengths and are used in sufficient quantity to provide for the necessary output of the detonator. PETN is the explosive most commonly employed as the detonator base charge. It is probably possible to use other materials with similar properties, for instance RDX.

Metals for components. The detonator cup, the bridge wire, and the wire leads of electric detonators are usually constructed of metal. The cup has been consistently made of gilding metal, while nichrome or platinum alloys have been used for the bridge wire. The wire leads are usually tin-plated copper. In choosing the components, the factors usually considered are compatability, adequate strength, and ease of manufacture.

Examples of Electric Detonator Design

The following examples of electric detonator design are taken from Navy mine and torpedo firing mechanisms and from Army bomb and projectile fuzes. It should be kept in mind that for some fuze applications the ignition elements would be dissimilar in that the electric fuze detonator would be designed for lower energies. Hence bridge wires would be of small diameter and length and made of materials of high strength, probably of tungsten and nichrome.

Electric Detonator Mk 46 Mod 0. This detonator (fig. 4–5) is sufficiently powerful to initiate a booster pellet directly. It is well sealed against moisture and employs comparatively stable explosives so that its surveillance characteristics are good. The base end of the detonator is rounded to minimize the tendency toward axial projection of metal fragments. This characteristic makes it unlikely that the booster will be initiated in case the detonator explodes in the safe position in devices where, on arming, the detonator moves along its

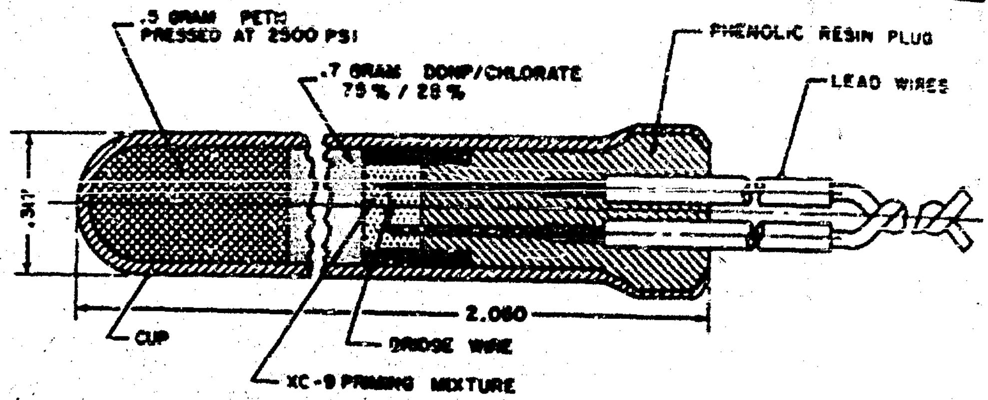

Figure 4–5. Electric Detonator Mk 46 Mod 0.

axis into a cavity in the booster and does not have a barrier between it and the booster when in the unarmed position.

The ignition element consists of the leads molded within a phenolic plug, the tophet-C bridge-wire 0.00225 inch in diameter and 0.075 inch long, the charge ferrule, and the ignition charge of buttered XC–9 mixture. The lead wires are of special design, a single strand lead wire being silver soldered to a stranded wire. The lead wires must be able to withstand considerable twisting.

The base charge consists of PETN pressed at 2500 psi in the gilding metal cup.

The intermediate charge consists of DDNP/$KClO_3$ 75/25 loaded loose and pressed to length by the ignition element at assembly.

Electric Detonator Mk 51 Mod 0. The ignition element consists of the same components as the Mk 46 except that the bridge wire is 0.0005-inch tophet-C of proper length to give a resistance of 2–6 ohms, and the lead wires are single strand all the way through. (See fig. 4–6.)

The intermediate charge is undiluted DDNP which is loaded loose and pressed to length by the ignition element at assembly.

The base charge is loaded in two increments, the one adjacent to the intermediate charge being at a lower pressure than the other. This plan allows the first increment to ignite more readily while the second, being loaded at higher pressure, gives greater output. The cup for this detonator is also drawn gilding metal. The drawing process normally produces a cup having a base which is thicker than its side walls. The indentation in the base reduces the thickness at this point and also gives some shaped charge effect to further offset the thicker section in the base of the cup.

Army Electric Detonator M36. (See fig. 4–7) The Ignition Element of this detonator consists of the wire leads molded within the phenolic plug, the 0.0005-inch diameter nichrome bridge wire, the

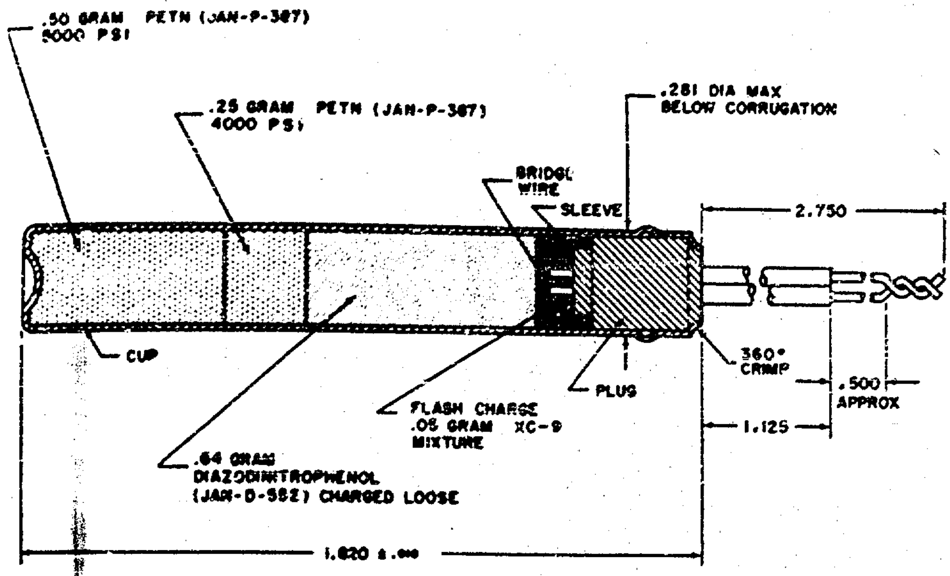

Figure 4–6. Electric Detonator Mk 51 Mod 0.

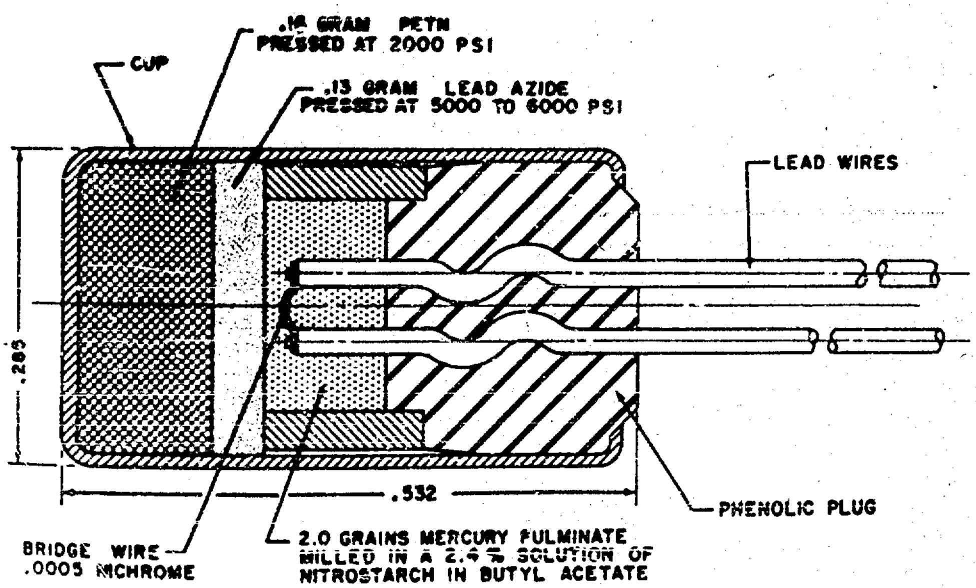

Figure 4–7. Army Electric Detonator M36.

fiber charge ferrule, and the mercury fulminate priming charge loaded therein.

The intermediate charge consists of lead azide pressed at 5000–6000 psi in the gilding metal cup. The interior of the cup is painted with a mixture of shellac and aniline so that the copper will not be in direct contact with the lead azide, with which it is not compatible.

The base charge is PETN, which in this instance is loaded at 2000 psi.

Input Characteristics

The design of the electric detonator for input requirements does not differ from that of the electric primer, as the input requirement resides in the ignition element whose construction is identical for both items. The factor differentiating detonators from primers is the much greater output of the former. The necessary design data and practice for the electric primer is covered in detail in section 3 of chapter 3 (page 3–22), and this material is equally applicable to the design of the input characteristics of the electric detonator. The reader is therefore referred to that section.

Output Characteristics

General. In the design for output of the detonator, there are two major considerations: (*a*) that the detonator have sufficient strength to initiate the next train item, that is, the tetryl lead-in or booster, and (*b*) that the fuze be safe against accidental firing of the lead-in or booster in the unarmed position. The design for output usually follows a system of cut-and-try wherein the weight of base charge is the major variable. The cut-and-try system becomes necessary because at present it is not possible to evaluate the factors affecting the necessary output. This situation is partly due to the fact that the power required is a function of the environment of the detonator. For instance, if the detonator needs to fire through only a thin barrier or short gap in a small volume with perfect lead alignment, then less output is necessary than when firing through large gaps or thick barriers in housings of large volume where lead alignment is not good. Although these qualitative effects are well known, the exact quantitative definition of these factors has not been established. A more detailed consideration of this subject is given in section 3 of chapter 8 (page 8–11).

There usually are two ignition transfers within the detonator: from ignition element to intermediate charge, and from intermediate charge to base charge.

Ignition element to intermediate charge. The intermediate charge is a highly sensitive explosive, and there is ordinarily no problem in effecting ignition of this material. It will be noted, however, that in most cases the intermediate charge is loaded loose and pressed to length with the ignition element. The reason is not to facilitate the initiation of this charge, but rather to provide a variable length of charge so that freedom from vacant spaces is obtainable, together with provision of room for forming a good crimp around the detonator plug. It is very probable that under these loading conditions, maximum efficiency of output from the intermediate charge is not obtained

Highly brisant explosives which may be brought rapidly to detonation over very short lengths should be used for this charge. The choice should be made on this basis and not on the basis of the various sensitivities such as temperature or ease of ignition by hot wires. For instance, lead styphnate is more sensitive to temperature, static electric discharge, or ignition by hot wire than is lead azide; but lead azide would, all other factors being equal, make a better choice for an intermediate explosive because it is brought to detonation more rapidly than is lead styphnate.

Intermediate charge to base charge. Detonating the base charge and obtaining enough power therefrom to initiate the lead or booster is slightly more complicated than the ignition of the intermediate charge. The base charge, usually being a high explosive, is per se more difficult to bring to detonation than the other materials in the detonator. For this reason, the more sensitive high explosives (such as PETN) are usually chosen for the base charge. In some instances, the loading is done in two or more increments; the increment to be actuated by the intermediate charge being loaded at a lower density to facilitate initiation, while the other increments are loaded at higher pressures to produce higher detonation velocities and more efficient output. The desirability of this practice is questionable, however, since recent tests have failed to support the assumption that a low density base charge is necessarily easier to initiate.

In many cases the base charge is loaded in a single increment, which ordinarily has a lower density than the final increment of a multi-increment loaded base charge. This type probably does not give as high a detonation velocity for the base charge. The factors dictating the type of loading that should be used are not clear. It is probable that, where the weight and length of base charge are fairly large, it is more efficient to use the increment loading; where these are small, there is probably little to be gained by such a loading procedure. No matter which technique is used, the usual procedure is to select a base charge weight large enough to effect high-order initiation of the lead plus enough excess base charge to give a reasonable surety of functioning, but not large enough to make the base charge so powerful that the fuze is unsafe in the unarmed position.

The output of electric detonators may be measured by sand bomb, Hopkinson bar, copper block, or lead disk tests. These are discussed in section 2 of chapter 9, under the topic "Initiators of Booster Type Explosives (Detonators and Leads)" (page 9–31). In general, such tests are useful for comparative purposes during detonator development work and for purposes of specification and production control. Preliminary data indicate that the results from such tests may be of value in

connection with the prediction of the performance of detonators from the standpoint of initiating leads.

Section 4.—References

Parenthetical numbers preceded by the letter "S" are Naval Ordnance Laboratory file numbers.

(1) Ordnance Drawing No. PX–7–308, **Detonator Loading Data.** January 15, 1944.

(2) Picatinny Arsenal Technical Report 1450, **Compilation of Data on the Composition of Foreign Primers and Detonators.** September 28, 1944. (S–13728).

(3) NOLM 8850, **Instruments for Sensitivity Testing of Flash Type Initiators, 1. Flash Detonator Tester (torch type), 2. Flash Detonator Tester (gas blast)**, C. J. Zablocki. November 22, 1946.

(4) NOLM 10401, **Detonator Test Set Mk 174 Mod 0 for Sensitivity Comparison of Flash Initiated Detonators (also referred to as the Oxy-Hydrogen Flash Detonator Tester)**, C. J. Zablocki and F. W. Hayward. September 30, 1949.

(5) NAVORD Report 2110, **The Relationship Between Sensitivity and Loading Pressure for Stab Type Priming Mixtures**, by G. U. Graff and R. T. Skelton.

(6) U. S. Army Specification No. 50–78–7. **Detonator Loading Assembly and Packing.** November 7, 1946.

Chapter 5

CHARACTERISTICS OF DELAYS AND DELAY ELEMENTS

Delays, as used in missile fuzes, are usually employed to secure enhanced damage by allowing the missile to penetrate the target to the optimum depth. They may also be used in a wide variety of applications when it is desired to have one operation follow another after the elapse of a preselected time interval.

There are many methods of securing delays, but the present discussion is limited to delays that are inherent in the ignition and burning of materials incorporated into the explosive train. Such materials may be pyrotechnics, propellants, or explosives, depending on the delay times desired. In any case the practical delay times obtainable by such means are relatively short, normally less than a minute.

Delays that depend on rates of burning of various materials are simple, cheap, and compact, but they may lack the precision which is obtainable with mechanical delays, particularly for long delay times. In general, burning delay times of one second and above are reproducible within about plus or minus 10 percent. For delay times of 0.01 second and less, the dispersion may be 50 to 100 percent.

Incorporated in the explosive train, the delay may be a separate physical unit called a delay element, or it may be integral as in the case where it is inherent in the ignition and burning of the explosives used.

Delays are normally incorporated into the explosive train in the form of a unit called a delay element or delay element assembly. This may consist of a primer, baffle, delay body (containing the delay material), and some sort of auxiliary charge at the terminal end of the delay column to transfer the burning impulse to the next item in the train. In specific instances, one or more of the above items may be omitted. The auxiliary charge may consist of a black powder charge, a detonator, or of some other explosive charge, depending on the requirements of the next item in the train. This charge may or may not be loaded into the delay body cavity.

For convenience of discussion, delay elements have been classified according to the type of delay material employed. These may be designated as black powder delays, gasless delays, and delays employing various other materials.

Section 1: Black Powder Delay Elements

General

Black powder has been long and widely used as a delay material. Its popularity may be largely attributed to its good dry surveillance characteristics, its ease of ignition, its wide availability in reproducible quality and granulation, its ease of loading, and its versatility from the standpoint of delay times obtainable. By proper control of available variables, it is practical to obtain delay times of from 4 milliseconds to 1 minute with this single material.

Black powder produces gases on burning, and the burning rate is affected by pressure. Hence the disposition of the gases is a primary consideration in the design of a black powder delay. If the gases are confined and not allowed to escape, the delay element is said to be obturated, while if the gases are allowed to escape the delay element is said to be vented.

Black powder delay elements may be further classified as column and ring types, depending on the shape of the delay cavity containing the black powder.

A detailed discussion of the various types is presented in the following paragraphs.

Obturated column type. Examples of the obturated column type of delay element are shown in figure 5-1, parts A and B. These and other obturated column delay elements are presented in greater detail in figures 5-2 to 5-10 inclusive. The firing pin (fig. 5-1, part A) on being actuated, fires the percussion primer, which spits into the expansion chamber and ignites the delay column without rupturing the primer cup. The column burns cigarette fashion, the gases being held in the expansion chamber, the primer cup, and the burned out part of the delay column. At the terminal end of the column, the burning black powder ignites the relay detonator.

The characteristics of this type of delay column may be summarized as follows:

(*a*) Time range: 0.01 second to 0.40 second. (The upper limit given represents general practice; however, it is possible to exceed this.)

(*b*) Use: It has wide application in contact initiated projectile and bomb fuzes of both the armor piercing and non-armor piercing types.

(*c*) Advantages: Simple, reliable, accurate. Not affected by changes in atmospheric pressure.

(*d*) Disadvantages: Narrow time range.

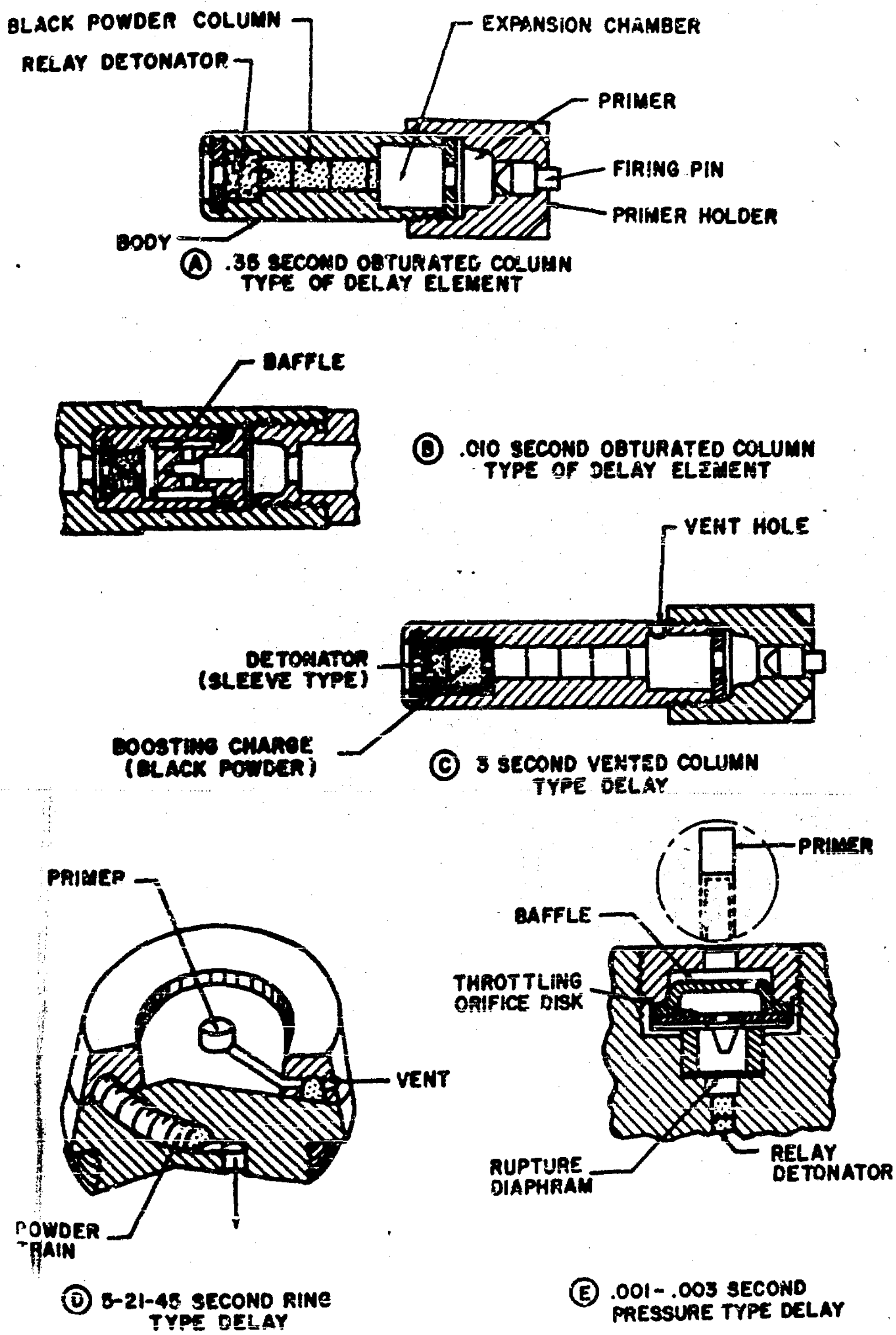

Figure 5–1. Various Types of Delay Elements and Delays.

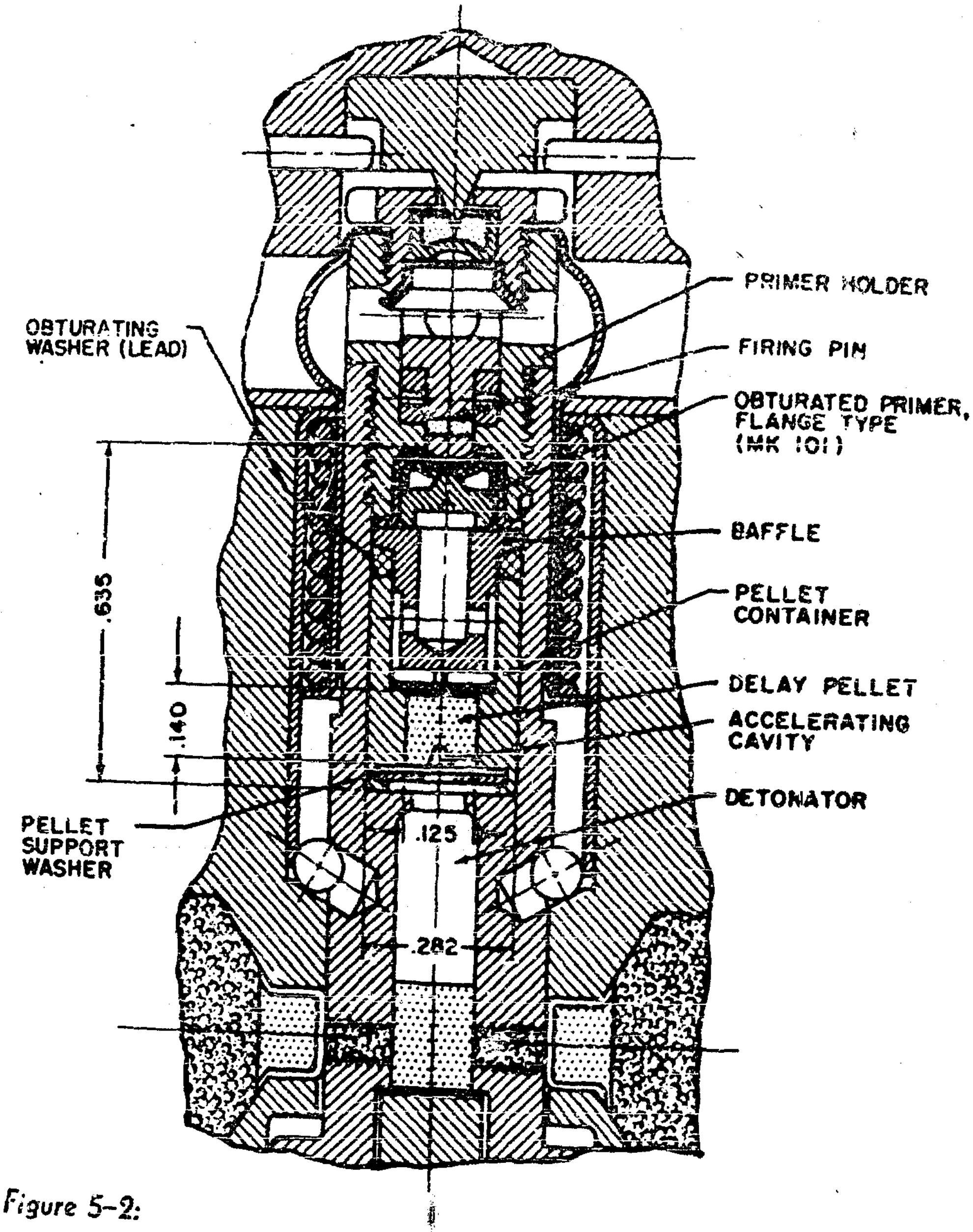

Figure 5-2:

Delay Type: Column; Obturated; With Baffle. (Shown in Firing Position).
Time 0.033 (± 0.005) Second.
Loading: 0.05 Gram A-5 Black Powder, Loaded in Place in Single Increment at 81,000 psi.
Application: Navy Base Detonating Fuze Mk 21 Mod 1. BuOrd Drawing 225563.

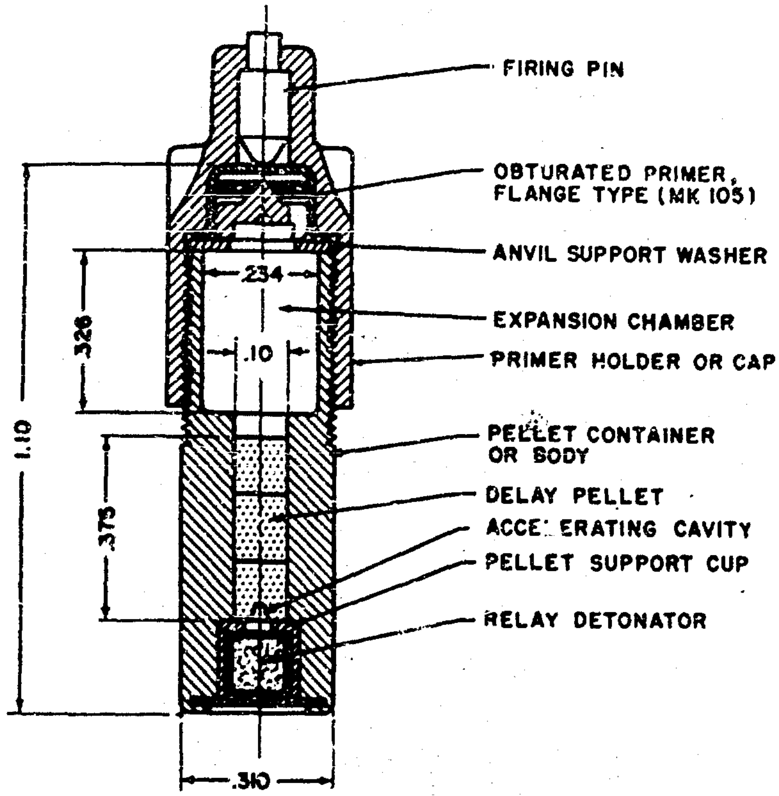

Figure 5–3:

Delay Type: *Column; Obturated; Without Baffle.*
Time: 0.33 (+0.05 −0.03) second.
Loading: 0.09 Gram D–55 Black Powder, Loaded in Place in 3 Equal Increments at 65,000 psi.
Application: Navy Bomb Fuzes Mk XXI Mod 2 and Mk XXIII Mod 2. BuOrd Drawings 234553 and 234554.

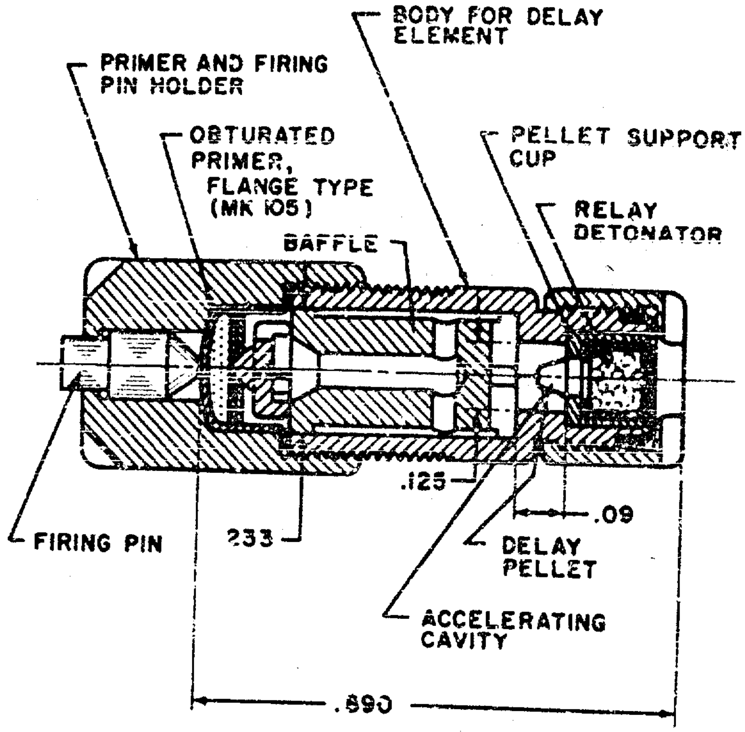

Figure 5–4:

Delay Type: Column; Obturated; With Baffle.
Time: 0.010 (+0.002 −0.0015) Second.
Loading: 0.025 Gram Meal D Black Powder, Loaded in Place in Single Increment at 65,000 psi.
Application: Navy Bomb Fuze Mk 221 and Mk 223. BuOrd Drawings 206618 and 202619.

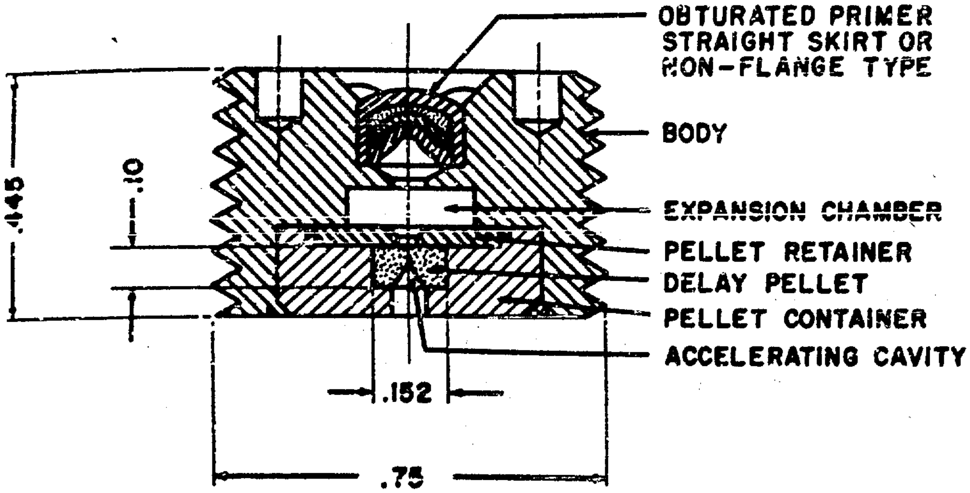

Figure 5–5:

***Delay Type:** Column; Obturated, Without Baffle.*

***Time:** 0.010 Second.*

***Loading:** 0.065 Gram A–5 Black Powder, Loaded in Place in Single Increment at 60,000 psi.*

***Application:** Army Base Detonating Fuze M68. Army Ordnance Drawing 73–2–181.*

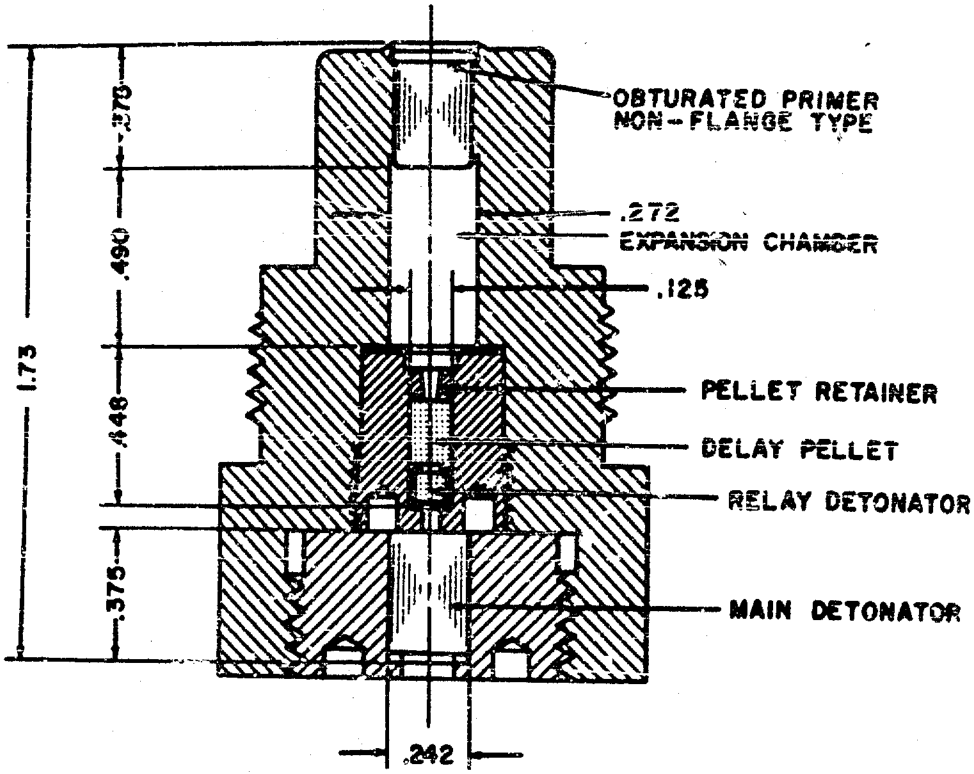

Figure 5–6:

Delay Type: Column; Obturated; Without Baffle.

Time:

0.010 Second.
.025 Second.
.100 Second.

Loading:

0.005 Gram A–5 Black Powder.
.014 Gram A–5 Black Powder.
.066 Gram A–5 Black Powder.
Each Loaded in Place in Single Increment at 60,000 psi.

Application: Army Bomb Fuze AN–M100A2. Army Ordnance Drawing 73–8–3.

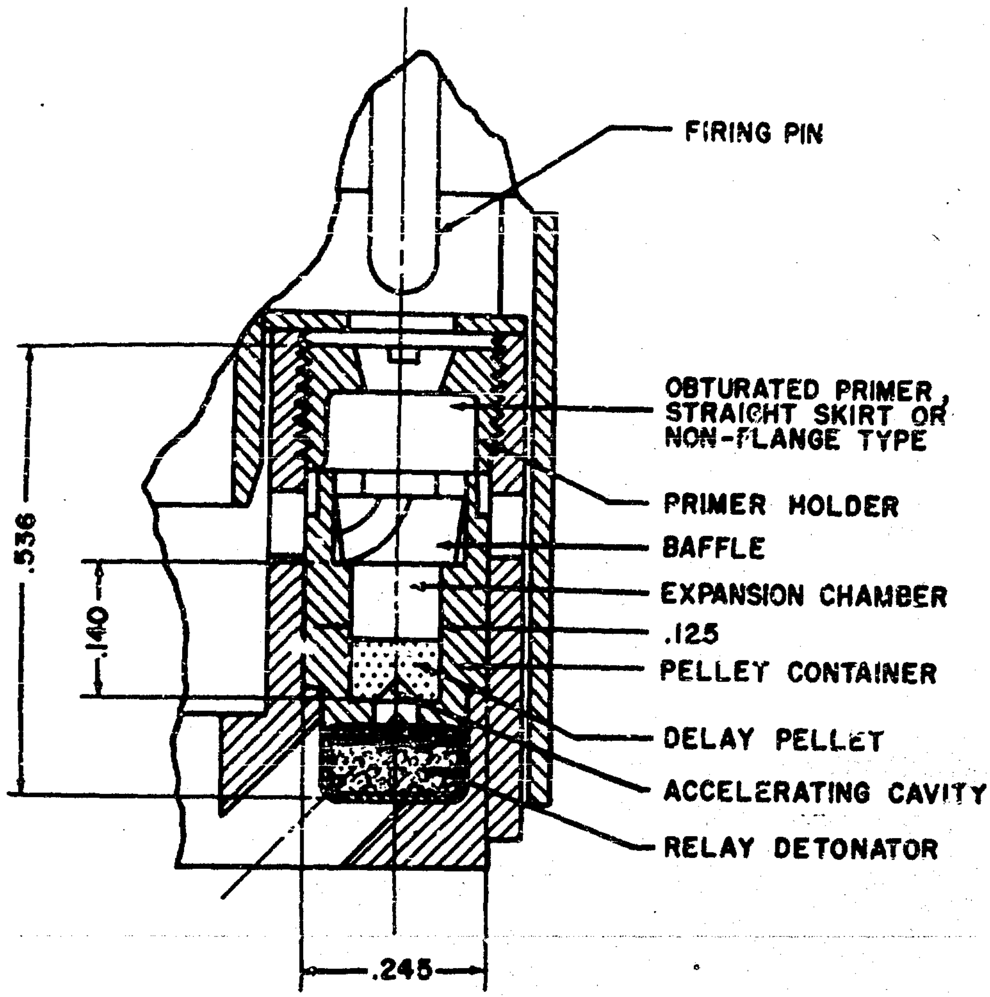

Figure 5–7:

Delay Type: Column; Obturated; With Baffle.
Time:
0.05 Second.
.15 Second.
Loading:
0.033 Gram A–5 Black Powder.
.046 Gram Black Powder (Approx. 80 Percent Slow Burning Black Powder and 20 Percent Fuze Powder Type I).
Each Loaded in Place in Single Increment at 60,000 psi.
Application: Army Point Detonating Fuze M48A2. Army Ordnance Drawing 73–2–145A.

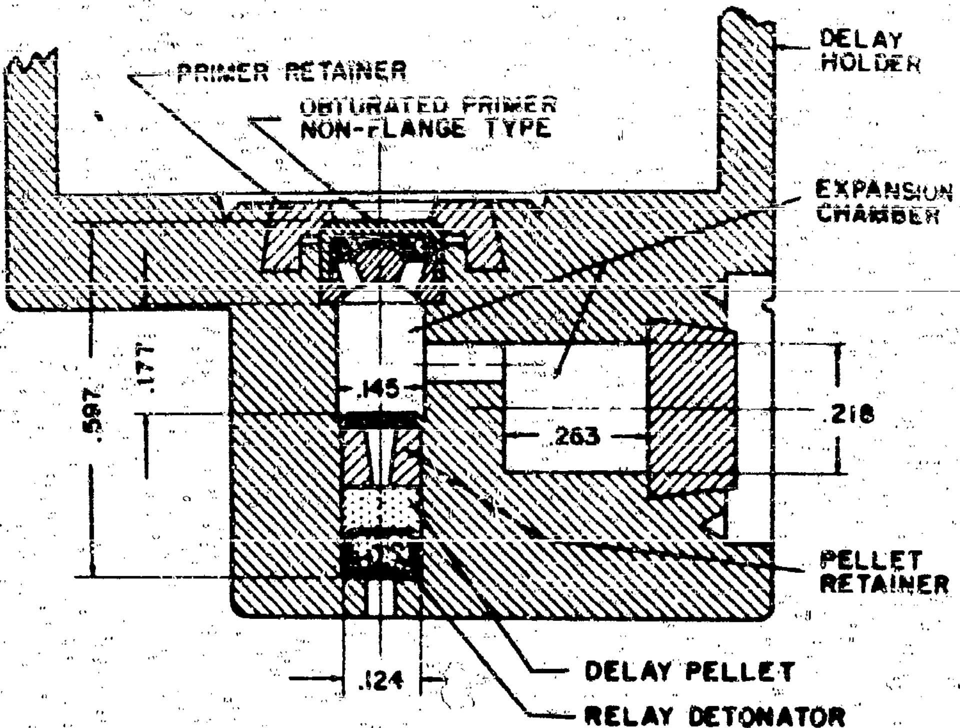

Figure 5–8:

Delay Type: Column, Obturated, Without Baffle.

Time: 0.04 to 0.06 Second.

Loading: 0.032 Gram A–5 Black Powder, Loaded in Place in Single Increment at 125,000 psi.

Application: Army Base Detonating Fuze M60. Army Ordnance Drawing 73–2–165.

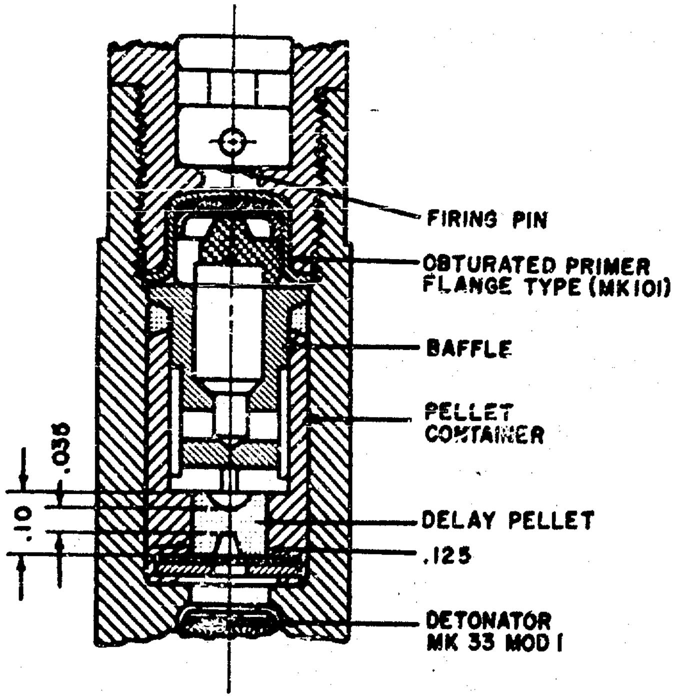

Figure 5–9:

Delay Type: *Column; Obturated; With Baffle.*

Time: *0.010 (+0.003 −0.004) Second.*

Loading: *0.031 Gram A–5 Black Powder, Loaded in Place in Single Increment at 73,000 psi.*

Application: *Navy Base Detonating Fuze Mk 19. BUORD Drawing 206213.*

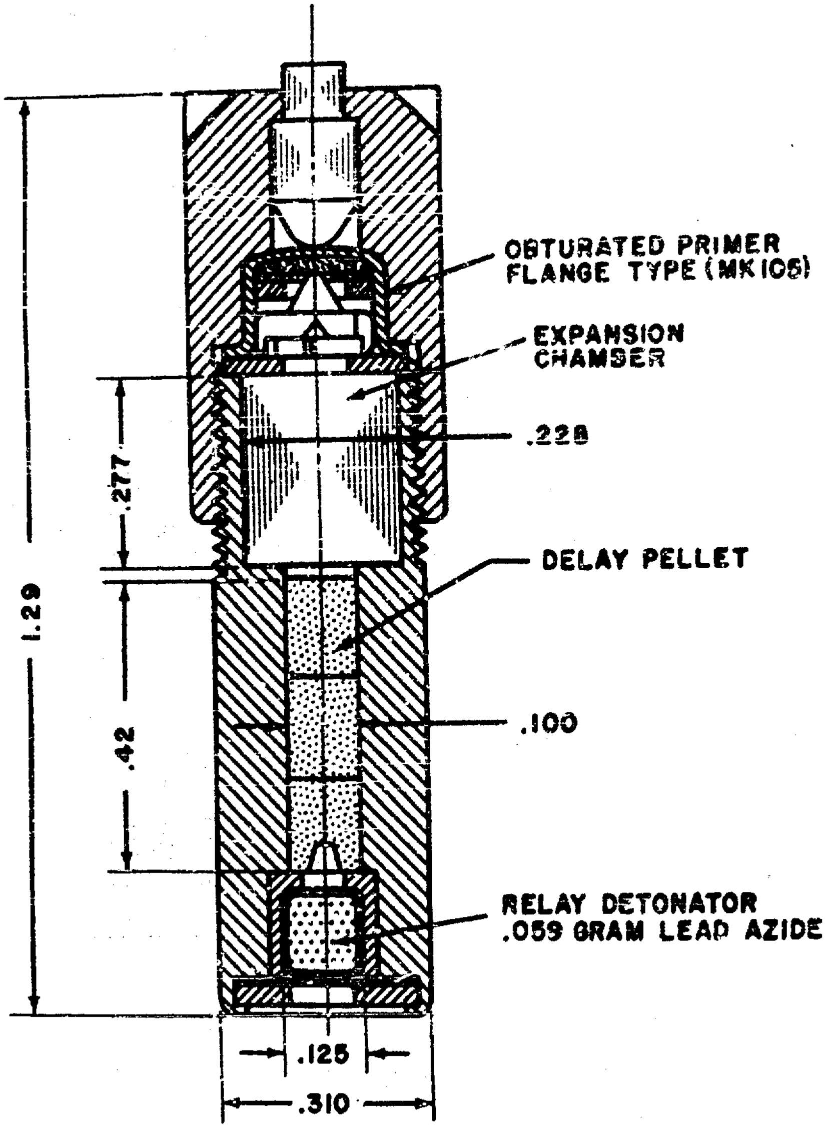

Figure 5–10:

Delay Type: Column; Obturated; Without Baffle.
Time: 0.25 Second.
Loading: 0.111 Gram D–55 Black Powder, Loaded in Place in 3 Equal increments at 65,000 psi.
Application: Experimental (XF3–B). NOL Sketch 87639.

Vented column type. An example of this type of delay is shown in figure 5–1, part C. The construction and functioning is very similar to that described under the obturated column type except that a vent is provided for the escape of the primer and delay-column gases. This type has the following performance characteristics.

(*a*) Time range: 0.50 second to 10.0 seconds. (These limits represent general practice as controlled by physical size. Actually, the

limits are probably 0.01 second to ∞. Delay times between 0.01 and 0.50 second are better obtained with the obturated column type.)

(*b*) Use: At present its application is restricted, and it probably finds its greatest use for fixed time aerial bursts, as in flares.

(*c*) Advantages: Broad time range, simple.

(*d*) Disadvantages: Sealing problem, needs large venting volume, tends to fail to ignite the relay detonator unless carefully designed and loaded.

Ring type delays. An example of this type is shown in figure 5-1, part D. Ring type delays are used mostly in time fuzes for aerial bursts where long adjustable delay times are desired. Such a time fuze is shown in figure 5-11. Another similar fuze of this type (not shown) has a time train of 45 seconds duration. As used in this type of fuze, the powder is pressed directly into the metal component (powder ring) of the fuze at 65,000–75,000 psi, then the powder ring and the powder are machined to given dimensions. This operation insures true, even surfaces of the powder and the metal ring. After facing, a shellacked paper disk is applied over the powder. At assembly a felt obturating washer is placed between the powder rings, as felt does not sustain combustion, but merely chars from heat. This type of delay is becoming obsolete and is being replaced by mechanical timing mechanisms. However, the principle of the ring type powder train could conceivably be used to advantage in other delay elements.

This type of delay has the following performance characteristics.

(*a*) Time range: 1.0 second to 45 seconds. (Limits represent general practice as controlled by tactical needs. Actual limits are probably 0.5 second to ∞.)

(*b*) Use: Formerly had wide application for aerial burst fuzes especially antiaircraft projectiles and in demolition devices. Largely supplanted by clockwork because of deterioration problems and variation of time caused from changes in atmospheric pressure along projectile trajectory.

(*c*) Advantages: Broad and adjustable time range.

(*d*) Disadvantages: Sealing problem, timing affected by changes in atmospheric pressure, expensive, bulky, expensive loading tools, considerable heat evolution.

Pressure type delays. The pressure evolved by burning black powder can be utilized to give delays in the order of 0.001–0.006 second. Such times are normally difficult to obtain with black powder delays which burn in train or cigarette fashion. The principle involves a rapid build-up in pressure which terminates by rupturing a disk or

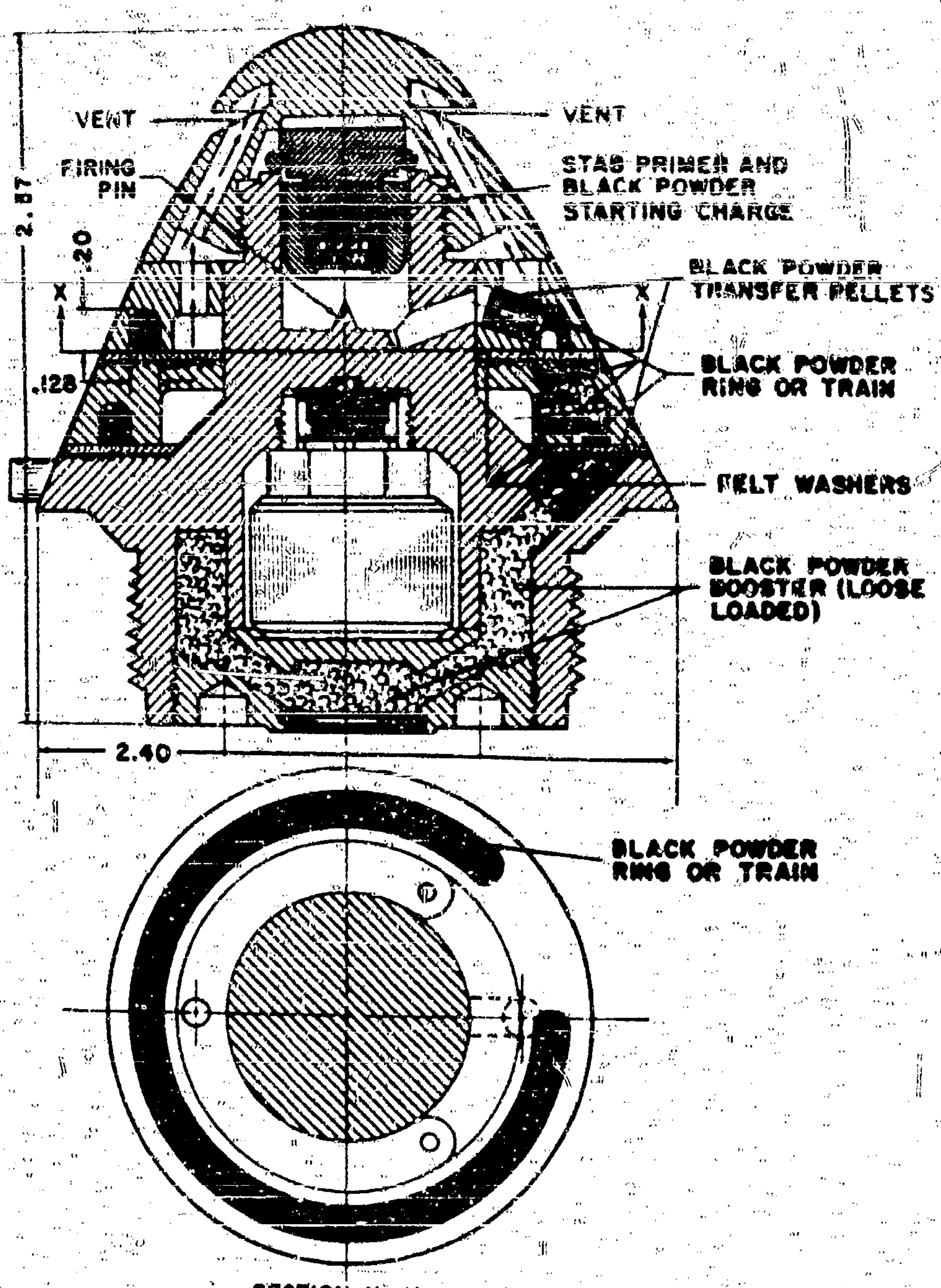

Figure 5-11:

Delay Type: Ring or Train; Vented, Without Baffle.
Time: Selective; 1 to 21 Seconds.
Loading:
Upper Ring—3.185 Grams.
Lower Ring—3.640 Grams.
A-7 Black Powder, Loaded in Place in Single Increment at 65,000 psi.
Application: Army Artillery Fuze 1918 Vintage Army Ordnance Drawing 73-3-114.

diaphragm. Designs based on this system can be obturated or non-obturated (vented). An example of such a delay is shown in figure 5–1, part E.

This particular delay is non-obturated and employs a stab type primer. Other essential features are a baffle, a throttling orifice, a lightly pressed powder charge and a rupture diaphragm. In operation, the powder charge is ignited through the throttling orifice (0.035 inch diameter); and the charge, being lightly pressed (4000 psi approx.), burns as a mass rather than in train fashion. The gases obviously flow back through the throttling orifice but are sufficiently retarded to permit a pressure build up which ruptures the diaphragm. This delay element, which has been successfully tested in a nose fuze for British 2 Pounder AA Ammunition is shown in greater detail in figure 5–12.

Another form of pressure type delay element is shown in figure 5–13. This delay element was designed for a Navy experimental fuze to provide a delay of about 0.004 second. It is similar to the delay shown on figure 5–12, but the housing is provided with four radial holes and connecting slots leading from the interior to a space in the fuze. This venting is for the purpose of relieving the pressure of the exploding primer which, due to its proximity to the powder charge, would otherwise cause instantaneous action of the delay.

It may be mentioned that the primers used in the delay elements shown in figures 5–12 and 5–13 are of about equal strength although loaded with different mixtures. However, because the assembled position of the primer in the former is comparatively remote from the powder charge and in such a position that sufficient space in the fuze is afforded for expansion, the disruptive action of the primer is so diminished that no special provision is necessary for relieving the pressure of the primer.

The critical features of the pressure type delay are:

(*a*) Brisance of the primer.
(*b*) Diameter of the throttling orifice.
(*c*) Strength of the rupture diaphragm.
(*d*) Loading pressure of the powder.

A correct balance between these features is necessary for proper functioning. No design data are available for the predetermination of the above values except such as have been compiled during the development of the two delays mentioned. A delay element of this type is frequently designed to conform to a fuze already in use in which very little change can be tolerated. As a result of this practice, the several parts may take on various shapes and sizes. However,

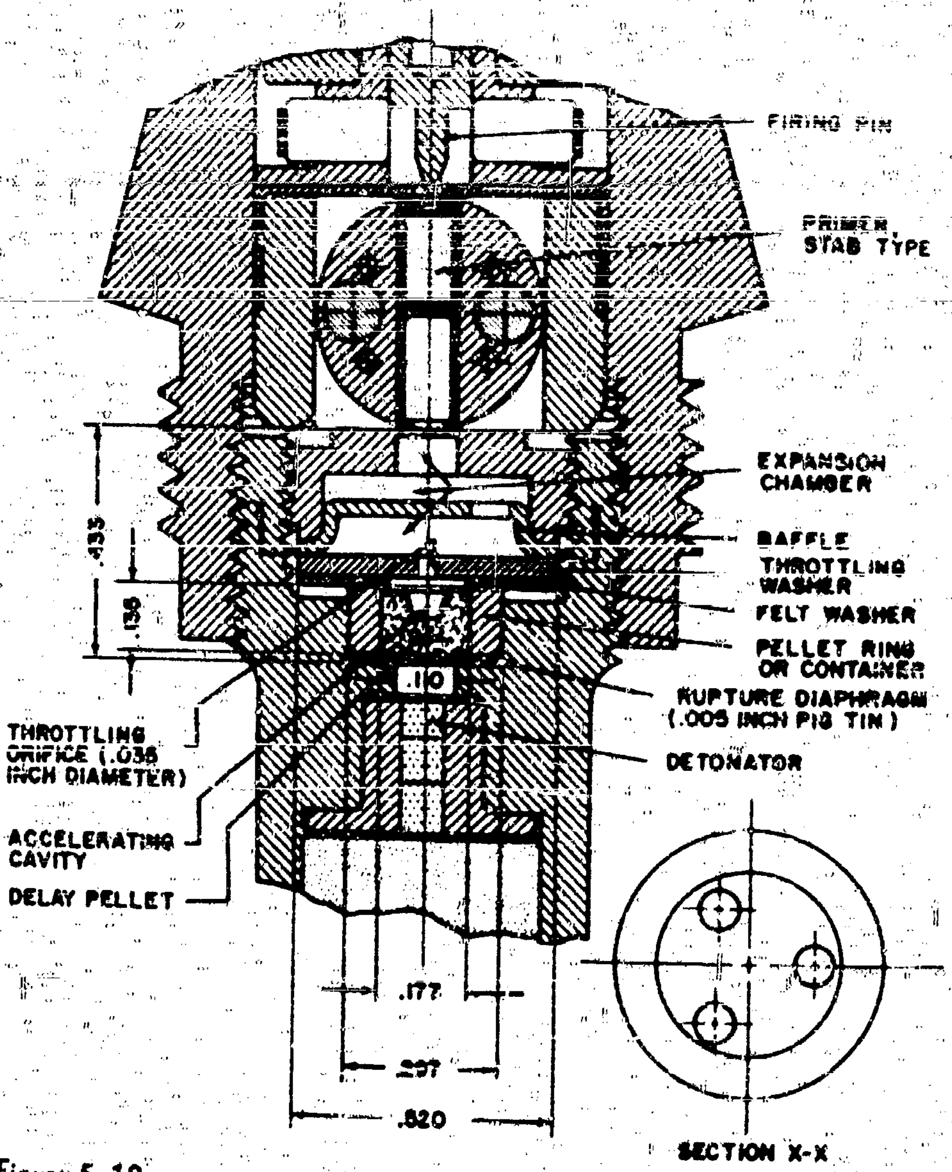

Figure 5–12:

Delay Type: Pressure, Vented, With Baffle.

Time: 0.001 to 0.003 Second.

Loading: 0.075 Gram A-5 Black Powder, Loaded in Place in Single Increment at 4,000 psi.

Application: British Point Detonating Fuze, NOL Experimental Version NOL Sketch 70998.

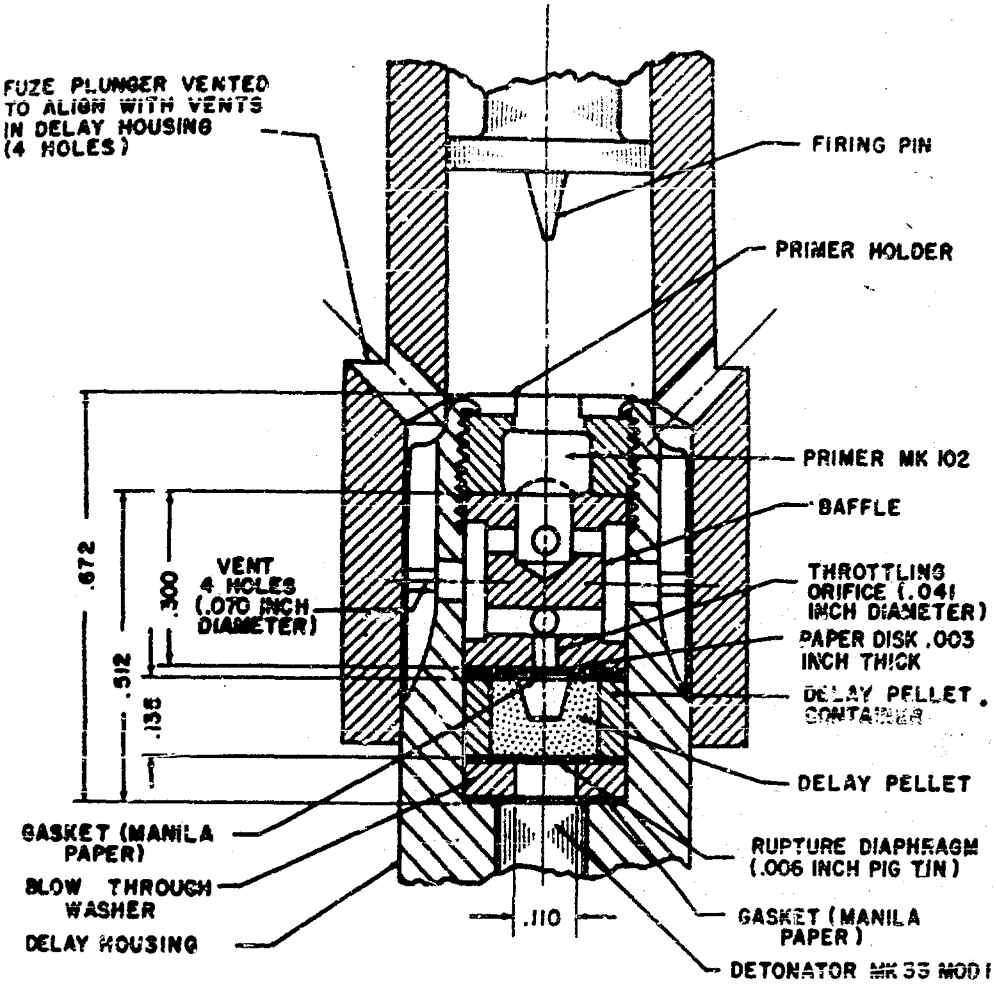

Figure 5–13:

***Delay Type:* Pressure; Vented; With Baffle.**
***Time:* 0.002 to 0.006 Second.**
***Loading:* 0.073 Gram A–5 Black Powder, Loaded in Place in Single Increment at 5,000 psi.**
***Application:* Navy Experimental Rocket Fuze, NOL Sketch 154417.**

the two delays illustrated serve as a general guide for future design problems (refs. (2) and (3)).

The performance characteristics of this type of delay may be summarized as follows.

(*a*) Time range: 0.0005 second to 0.01 second. (Limits represent general practice. Actual practical limits are probably 0 second to 0.10 second.)

(*b*) Use: Applicable to time delays below 0.01 second, times which cannot be obtained with any other type black powder delay. Applicable to projectile bomb or rocket fuzes.

(*c*) Advantages: Very short delay times, simplicity, compactness.

(*d*) Disadvantages: Great care needed in designing and loading.

Construction of Components

All types of black powder delays are made up of various combinations of the following components:

Delay Body	Primer Holder	Baffle
Black Powder Charge	Primer	Relay Detonator
Pellet Support	Firing Pin	Disks

In general (pressure type excepted), to utilize black powder as a delay device some provision must be made to confine the burning to a single surface and guard against ignition of the entire surface of the powder pellet simultaneously. This is usually accomplished by securing the pellet, column, or train in a metal body, the junction of the two being a very close fit, as is obtained by a pressing operation. A percussion primer is secured to this body, or in relation to it, by some method such as screw threads or crimping.

The primer housing, usually called the primer holder, may contain a firing pin or merely a hole through which to receive one when mounted in a fuze or other similar device. The function of the primer and firing pin is to ignite the black powder column or train at its exposed surface. At the terminal end of the black powder train a detonator or relay detonator is mounted in, or in fixed relation to, the delay body, usually by a crimping process. The function of the detonator is to receive flame from the black powder train and, by its own initiation, cause the device to function in its entirety.

Delay body. The delay body (pellet container) and powder ring are made of commercial brass wherever possible because of its ease of machining. In cases where severe shock conditions are to be encountered or very thin sections are required as necessitated by space limitations, the practice is to use naval brass or stainless steel.

In obturated delays, an expansion chamber is provided at the primer end of the body to cushion the shock of the primer gases and prevent excessive build-up of pressure as the delay pellet is burning. If no such chamber were provided, the high pressure would tend to (1) rupture the primer cup and/or burst the assembly thus destroying obturation, and (2) crack the powder pellet and move it as a piston relative to the body, permitting blow-by with resultant erratic times.

The bore of the body for column type delays is drilled and then

reamed to a tolerance of 0.0002–0.0004 inch. A smooth hole in the bore and concentricity between the bore and the expansion chamber within close limits are necessary to facilitate the use of a close-fitting loading ram and to obtain correct axial alignment. Otherwise, it would be necessary to align the loading ram with the bore. These precautions help to insure a sturdy pellet of uniform lateral density which fits so close to the bore as to minimize blow-by possibilities.

Visual inspection of the surface of the bore with a magnifying glass should disclose no tool marks or scratches running in an axial direction, as these are conducive to blow-bys.

Circumferential tool marks are not considered serious except where their size is such that the powder may be pinched between them and the ram; in this case, ignition may occur during the loading process.

Sharp edges (no burrs) are desirable at the ends of the bore. Since loading is effected from the primer end in most cases, the pellet is usually flush with the detonator end of the bore; any significant radius here tends to cause a lateral plane of weakness through the pellet with a tendency for a small portion to flake off, thus causing an imperfect pellet. If an excessive radius exists at the ram end of the bore, the powder charge will sift out under the funnel and be subject to initiation by the pinching action of the ram end.

It is necessary to maintain the body surfaces at the ends of the bore at right angles to the axis. This practice insures proper seating of the loading funnel and the pellet support at the terminal end. (See figs. 5-14 and 5-15.)

The delay body for the pressure type delay is less critical as regards bore diameter and sharp edges at the ends of the bore.

A tolerance of +0.001 to +0.002 inch on the diameter is satisfactory since blow-by of the primer gases is not critical with this delay.

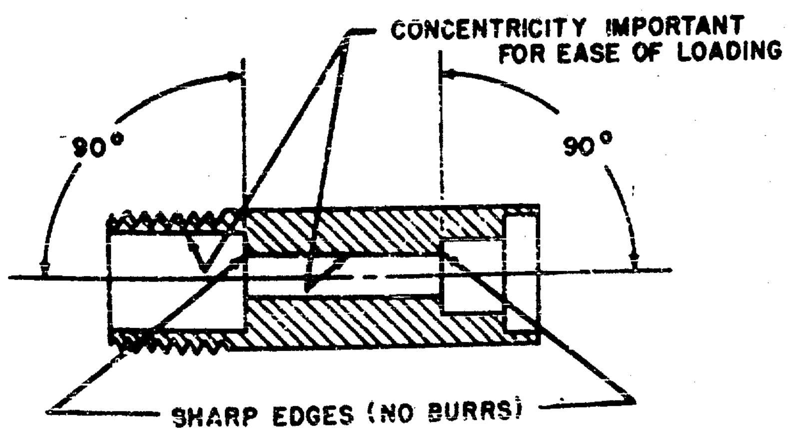

Figure 5-14. Some Pertinent Design Features of Column Type Delay Body.

Slight flaking of the pellet is not serious, since the accuracy of the burning time does not depend upon the effective length of the pellet.

Pellet construction and loading. Pellet construction is critical and should be given careful thought. All obturated column type delays should have an "accelerating cavity" formed in the terminal end by using a projection on the loading tool base. This cavity usually takes the form of a truncated cone and serves the important purpose of

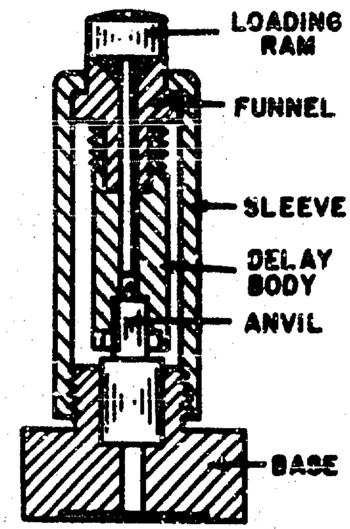

Figure 5–15. Typical Loading Tool.

increasing the area of the burning surface. This shape gives a final spurt to the flame and helps to insure good ignition of the succeeding element in the train.

The cone is designed with enough draft to permit easy withdrawal of the loading tool base without flaking off a portion of the pellet. The base diameter must not be so large as to seriously reduce the pellet support surface and allow the pellet to shift axially under gas pressure by crushing of the terminal end. The truncated shape is utilized to facilitate tool manufacture and obtain a closer tolerance on the depth of the accelerating cavity. A close tolerance is especially important in the case of short delays of about 0.01 second time. (See fig. 5–16.)

Increment loading of the delay column is utilized to obtain a more uniform density throughout. Pellets with a l/d ratio equal to one or less are usually loaded with a single increment. The upper limit for any one increment is l/d=2, with the general run being l/d=1.5. Uniformity in density is desirable to minimize blow-through possibilities, which tend to increase when the pellet is too soft toward the terminal end.

The top of the delay column should always be loaded below flush, say at least 0.02 inch, to compensate for expansion after removal of the loading pressure.

The action of the loading ram end causes a glazed condition of the black powder surface of all increments. This glaze is somewhat resistant to flame and in some few cases it may be found desirable to roughen the primer end of the column. The glaze between increments is usually not as detrimental, although it does cause a somewhat intermittent burning or puffing as the flame transfers from one increment to the next. In the event that trouble is experienced with extinction between increments, a step-type loading ram (fig. 33–17)

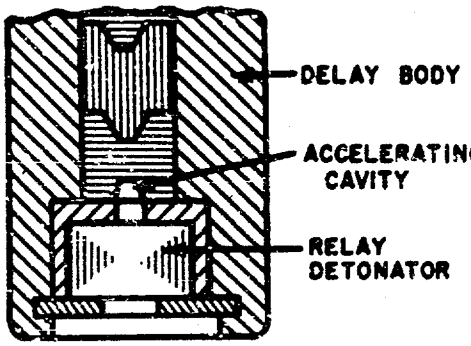

Figure 5–16. Position of Accelerating Cavity in Column Type Obturated Delay.

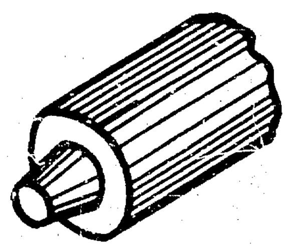

Figure 5–17. Step Type Loading Ram.

can be used to advantage (See fig. 5–17). Serrated or waffle type ram ends are impractical because of the small diameters involved.

The use of a step type ram increases the area of contact between increments and offers a better chance of flame transfer. Little or no use will be found for methods of overcoming the difficulties resulting from the glazed condition in column obturated delays, since the gas pressure is usually sufficient to overcome the reluctance of these surfaces to accept flame. Wide use of these methods may be found with the column vented type where little pressure exists. With this type, intermittent puffing between increments is readily observed because the smoke issues from the vent in puffs.

Venting arrangements. The purpose of vents is to release the gases produced by the burning powder, thus allowing burning at a lower pressure and consequently at a lower rate. The vents are often sealed or plugged before the delay element is assembled in order to protect the element from adverse atmospheric conditions and/or to facilitate the ignition of the powder. If the vent is not sealed, the requirement of surety of ignition of the black powder column by the primer will

limit the size of the vent, which in turn limits the amount that the burning rate can be slowed down to conserve space (ref. (1)). If the vent is too large, difficulty may be experienced in transferring ignition from the delay column to the relay detonator or to whatever item comes next in the explosive train. Another difficulty which may arise is the problem of disposing of the gases which are exhausted through the vent.

Any sealing of the vent should be broken as the primer is initiated; therefore, the seal cannot be too secure. Figure 5–18 shows two

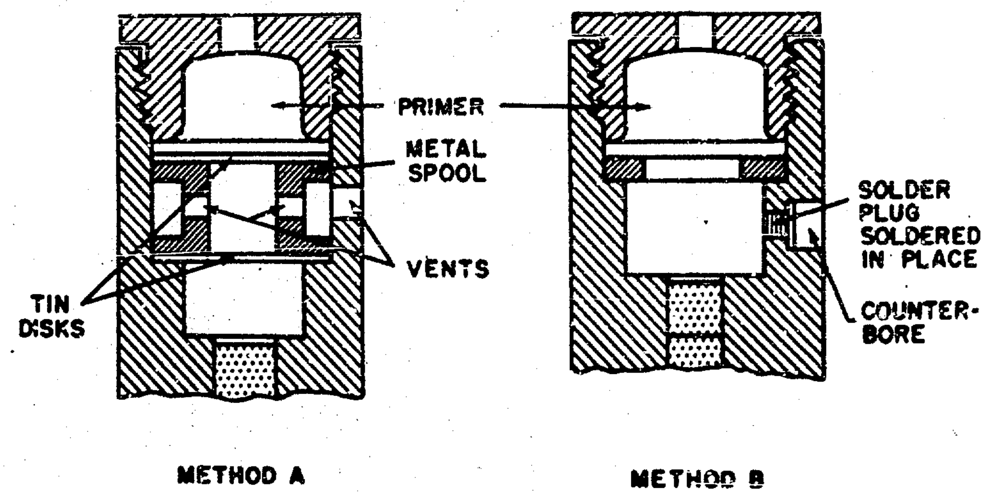

Figure 5–18. Two Methods of Sealing the Vent.

methods of sealing that have been tried. Method A is a seal that may be used successfully in some cases depending largely upon the physical dimensions of the delay body or housing. This method has been found to be unsatisfactory in delays of approximately 7 seconds housed in bodies of 0.310 inch diameter using D–55 powder. The spool was necessarily small, and the resulting clogging of the ports by the residues from the burning powder caused short delay times.

The seal labeled method B in figure 5–18 is preferred; under optimum conditions the solder would be expelled, by the heat and pressure of the primer alone, simultaneously with the ignition of the powder train. A solder that requires additional pressure and heat from the burning time train causes shorter times when the delay is functioning at low temperatures (such as −65° F). An encouraging degree of success has been obtained with this seal, although the optimum solder composition has not been determined. Figures 5–19 and 5–20 indicate the trends of burning times for delay elements with sealed vents and with open vents. A solder of 240° F melting point was used in the sealed

vents. In any case, the vent should not be too large, since it will tend to exhaust the primer gases excessively before ignition of the delay column occurs (ref. (1)).

The physical construction of the device in which the vented delay is assembled may present a serious problem, since interference with the free discharge of exhaust gases causes shortened burning time. Very few data are available on the relationship between the burning time and the volume provided for the entrapment of gases. However, a limited number of tests have been conducted on 7-second vented

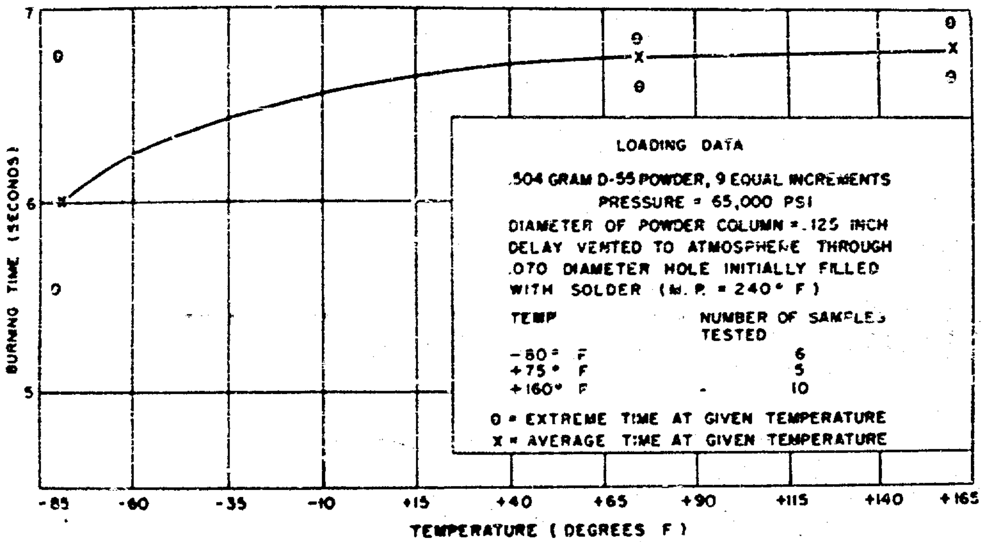

Figure 5-19. Burning Time vs. Temperature, Solder Sealed Vent in Delay Element.

delays enclosed in gas tight chambers of different volumes. The results of these tests are shown graphically in figure 5-21. The indications are that, to prevent appreciable shortening of the delay time, a chamber volume of 30 to 40 cubic inches would be necessary for the exhaust from this particular delay (ref. (1)).

Pellet support. Since any displacement of the black powder pellet relative to the pellet bore (body) is likely to cause blow-bys, some means must be provided to secure the pellet against the pressures developed during burning. Side-wall friction between the pressed pellet and the bore is, of course, always present; however, its limitation usually makes necessary an additional means of support. This friction is sufficient in itself during the initial stage of pellet combustion; however, it naturally disappears as the pellet is consumed, and little is left when the pellet approaches a wafer condition. If the pellet were unsupported, the last portion of it would be blown through.

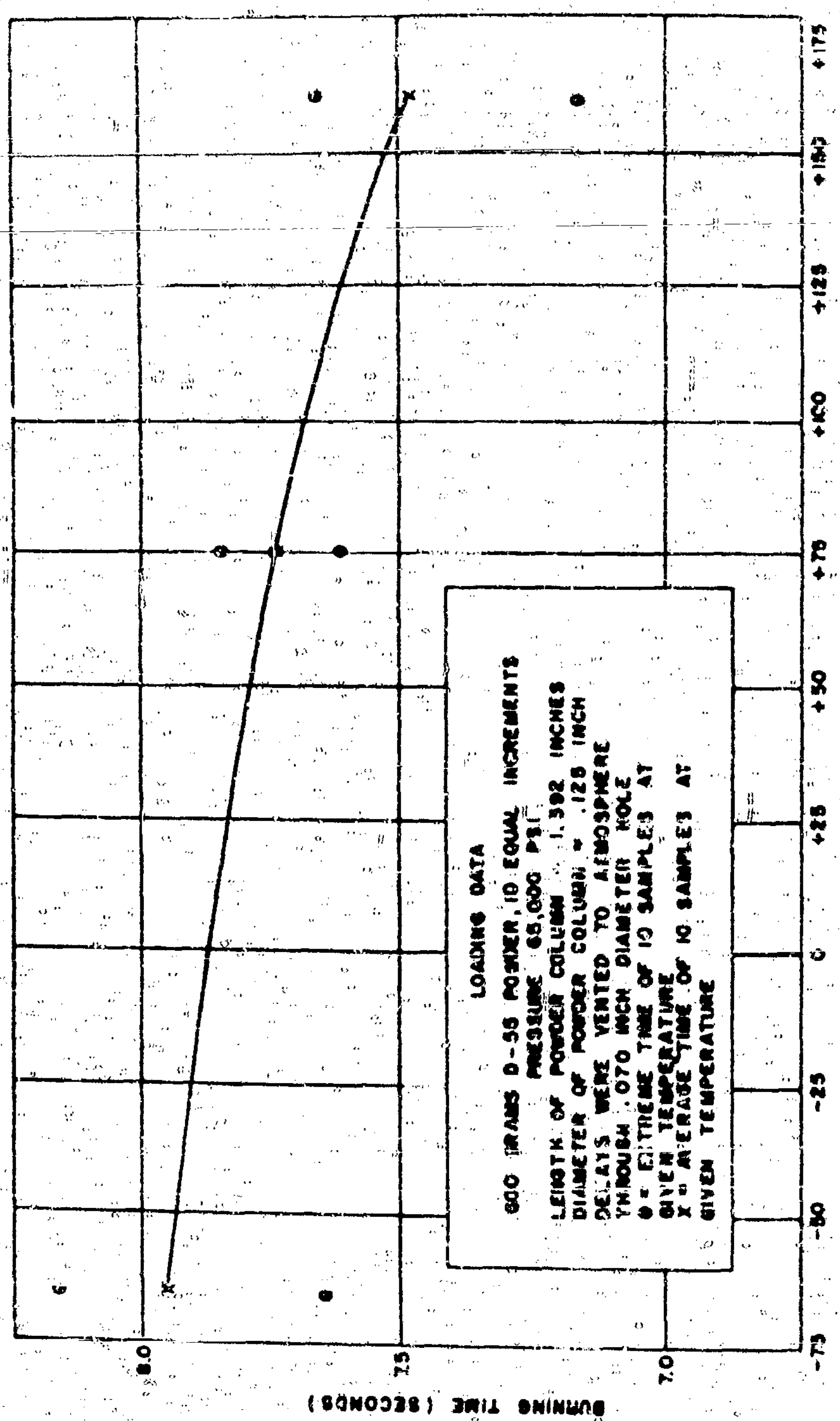

Figure 5-20. Burning Time vs. Temperature, Unsealed Vent in Delay Element, 7.7 Seconds Delay

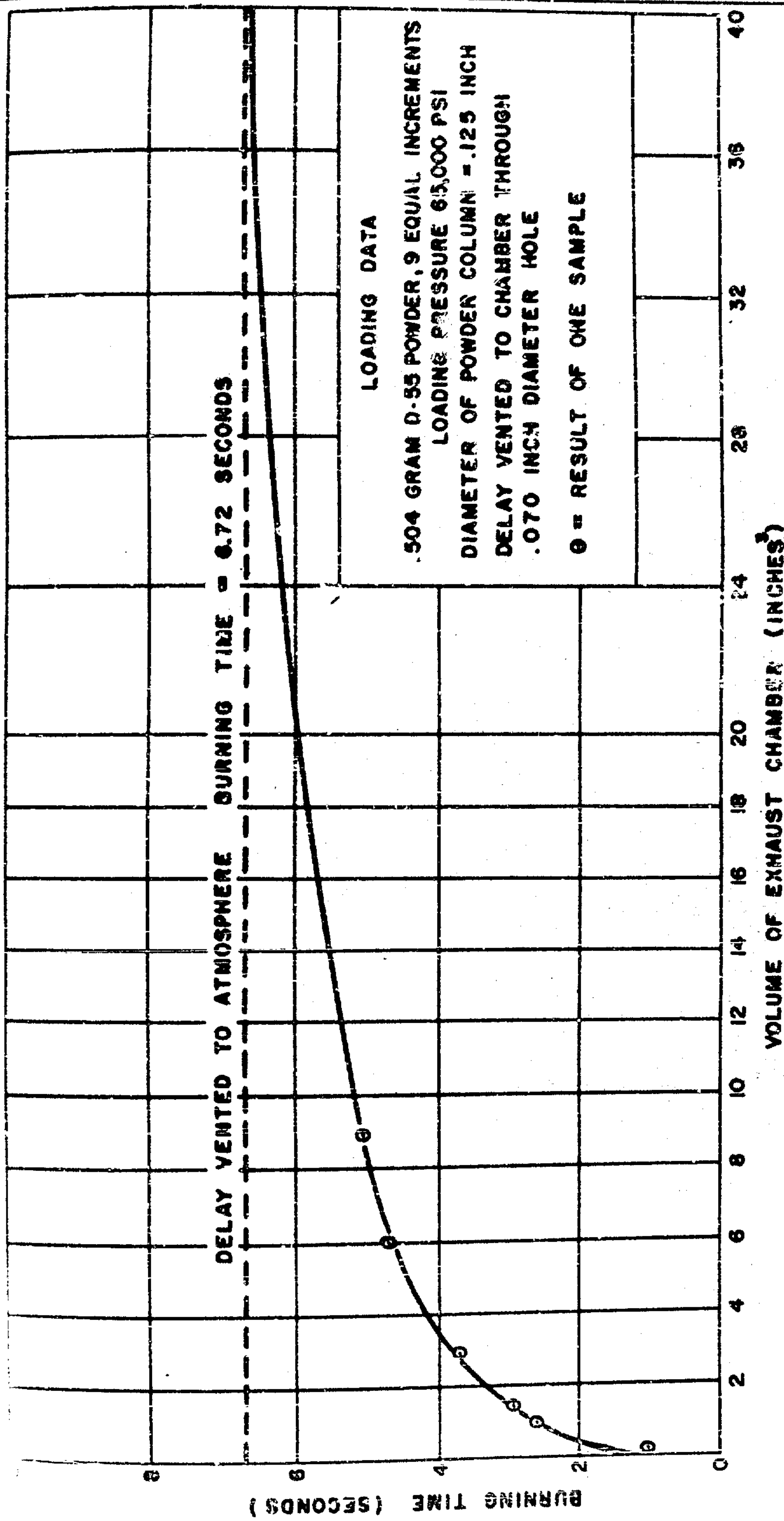

Figure 5-21. Burning Time vs. Volume of Exhaust Chamber.

In order to prevent initial or later-stage displacement of the pellet, the pellet support is included. This component is merely a flat metal surface held tightly against the terminal end of the powder pellet and having a hole of somewhat lesser diameter than the pellet. The outer edge of the support extends across the aft surface of the delay body, or container. Pellet supports are either washers or inverted machined cups. The material is usually stainless steel, brass, or dural. Two types of pellet supports are shown in figure 5–22.

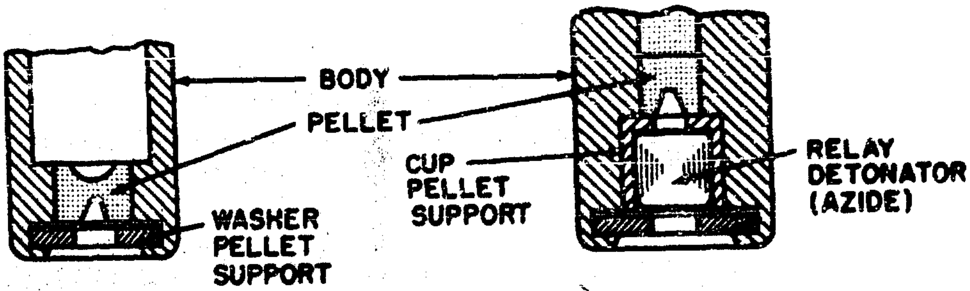

Figure 5–22. Pellet Supports.

Since unobturated (vented) delays have little pressure build-up, the pellet support is not as important; in some cases it may possibly be omitted.

The pellet support is usually assembled after the loading of the nelay column; therefore, the necessity for true surfaces on the termidal end of the delay body and the surface of the support can be seen. The reason for loading from the primer end of the delay column now becomes apparent. It insures flushness of the delay column, permitting a good contact with the pellet support.

Primer holder. The primer holder serves to (*a*) close the forward end of the delay element, (*b*) house the primer, and (*c*) to hold the firing pin, if an integral pin is utilized.

Materials and reasons for their selection are the same as those for the delay body. Mounting to the body can be effected by force fit, crimping, or screw threads. The last named process is most widely used and preferable, no doubt, since it minimizes leakage in the case of the obturated delays. Although somewhat more expensive, the results are considered well worth the difference.

The only critical details of this component are the contour of the cavity which accepts the crown of the primer, and the diameter of the hole to admit the firing pin along with the radius of the corner of this hole where it intersects the crown cavity.

The crown cavity of the primer holder should follow the primer contour and be reasonably close to it, say a few thousandths of an inch clearance. The need for this detail can readily be seen since the primer cup is necessarily thin for sensitivity reasons and requires support to prevent rupture from the internal gas pressure evolved during the burning of the delay. In the case of the non-flange primer, the crown cavity serves the additional purpose of permitting the primer cup to form to the cavity walls thus effecting a gas seal or obturation by virtue of the expansion of the primer cup by the internal pressure.

Possibly more critical are the physical characteristics of the hole which admits the firing pin. If the hole is too large an excessive

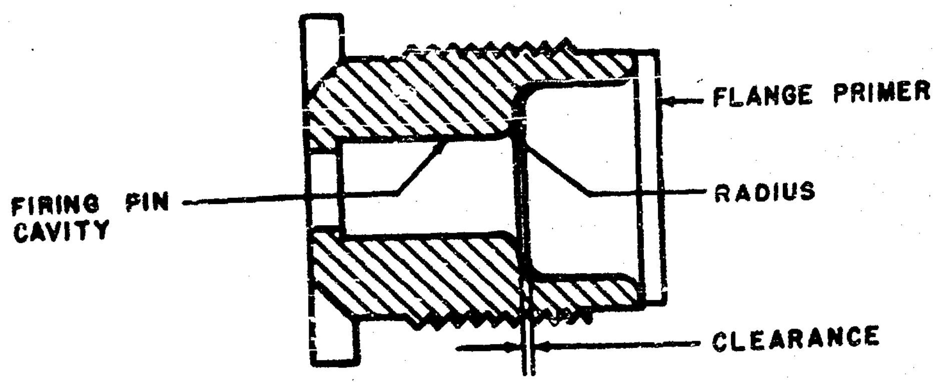

Figure 5-23. Primer Holder Detail.

amount of primer cup area is in an unsupported condition which is definitely conducive to blow-backs through the cup metal. Close attention must be given to the corners of this hole at its intersection with the crown cavity. There must be sufficient radius to prevent any sharp edges from acting as a die which tends to allow the gas pressure to cut out a disk from the crown of the primer cup. (See fig. 5-23.)

Finally, sufficient clearance between the top of the crown cavity and the top of the primer cup must be maintained at assembly to prevent any undue assembly pressure on the primer cup, which could cause deformation and fracture of the explosive charge in the primer.

Primer holder design is less critical with the vented delays, since internal pressure on the primer cup crown is less and a punctured primer cup has less effect on the performance.

Primer. Primers used in the delay elements are usually of a standard variety. The charge weight should not be so great as to cause deformation of the delay element metal components when

fired. Charge weights employed usually range from 19 to 26 milligrams. Vented delays (fig. 5–1, parts C and D) can, of course, employ non-obturated primers, which are usually considerably more violent than the obturated types. The main precaution to be observed in this instance is to guard against serious deformation of the delay's components and pellet or ring train.

Two general types of primers are now in use, the flange type and the non-flange type. (See fig. 5–24) Obturation is effected with

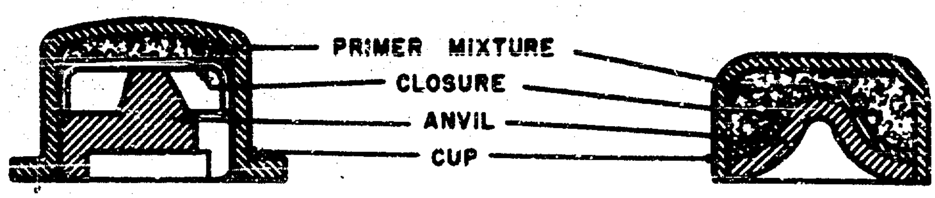

Figure 5–24. Two Types of Primers.

the flange type by compressing the flange tightly between two flat metal surfaces, such as the body and the primer holder, as well as by the expansion of the primer cup against the walls of the primer cavity. The non-flange type depends entirely upon the internal gas pressure expanding the primer cup against the walls of the primer cavity in the primer holder. The non-flange type is cheaper to manufacture; however, the flange type permits a better sealing of the delay element against atmospheric moisture.

Since, as pointed out before, the primer cup must be relatively thin for purposes of sensitivity, measures must be taken to prevent its rupture when deformed by the firing pin and when expanding to meet the walls of the primer cavity of the primer holder. This condition is met by controlling (*a*) the hardness of the primer cup metal, (*b*) the penetration of the firing pin, (*c*) the contour of the end of the firing pin, (*d*) the contour of the primer cavity, and (*e*) the clearance between the exterior surface of the primer and the walls of the cavity. The hardness specifications for Navy Primers Mk 101 and Mk 105 are 60 to 85 Vickers for the former and 65 Vickers maximum for the latter.

Firing pin. The usual material for firing pins is commercial brass, but dural and stainless steel have been used. In general, the pins are of the rounded-end type to prevent puncture of the primer cup, which would result in loss of obturation or in the case of vented delays cause an unpredictable venting.

Control of firing pin penetration is of utmost importance to prevent rupture of the primer cup or undue deformation of the components. Two methods of control are shown in figure 5–25. For Navy Primers Mk 101 and Mk 105, for example, penetration should be controlled within the limits of 0.032 inch –0.043 inch. The pin can either be part of the assembly or a separate item.

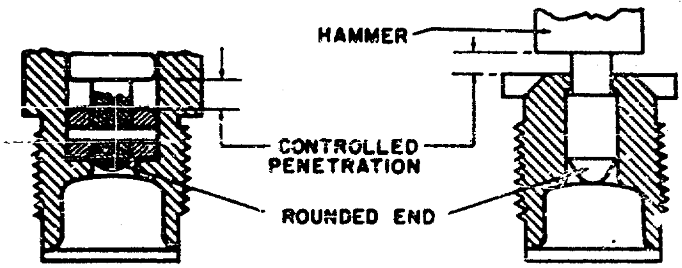

Figure 5–25. Control of Firing Pin Penetration.

In the case of pins which are parts of the assembly, it is sometimes desirable to make them of dural since the pin usually floats on the primer cup and a lighter pin enhances drop test safety.

Baffle. When the primer is initiated, a high velocity jet (hot gases, slag particles, and fragments of the closure disk or cup) is projected toward the black powder pellet. The inertia of these blast components is such as to cause undue penetration of the pellet's surface thereby disrupting a portion of it and affecting the delay time. Such a condition is exceptionally serious with obturated delays of small time magnitude, say 0.01 second, where the impingement of these combustion products will usually completely disrupt the very small pellet, giving no significant delay. Longer delays, say tenths of a second, are not so seriously affected. Blow-through (complete disruption) here is not likely, and time tolerances are usually large enough to absorb the effect of pellet damage.

To combat this disruptive force, a baffle is utilized. Baffles have many forms, but all serve to absorb the energy of the slag particles and sealing device fragments by deflecting them. An additional function is to reduce the velocity of the hot primer gases and "ease" them across the surface of the pellet.

Baffles are usually made of commercial brass or aluminum alloy for machineability. Occasionally stainless steel is employed where the body and primer holder are of this material. The purpose is to avoid dissimilar metals in order to reduce the possibilities of electrolytic corrosion.

The size of the baffle is usually dictated by space limitations. However, it must be large enough to provide channels of sufficient

size to prevent excessive back pressure on the primer cup, which may cause rupture. Channels may be large enough to prevent primer cup failure and yet of insufficient size to permit proper ignition of the pellet. In this case, excessive cooling of the primer gases is the cause of faulty ignition. It is probably safe to say that the channels or ports should be made as large as is commensurate with structural strength of the component and still not permit direct impingement of the products of combustion on the pellet.

Decision as to when to use a baffle is determined by the structural strength of the pellet and the accuracy of timing desired. Very short delays, say 0.01 second, will require the baffle by reason of the

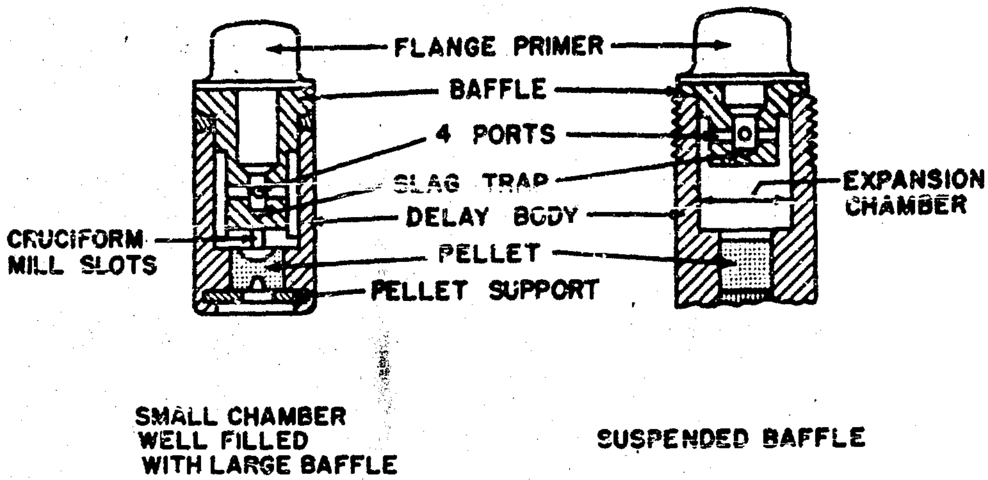

Figure 5–26. Two Types of Baffles.

small pellet. To obtain the utmost in close time tolerances, a baffle should be used. Two types of baffles are shown in figure 5–26.

In the event that a short delay is desired but space limitations preclude the incorporation of any baffle, the pellet should be pressed at very high pressures to offer resistance to penetration of the high velocity particles. The pressure is accomplished at some sacrifice of reproducibility and shortness of delay time.

Relay detonators. After expiration of the delay time, a substantial spurt of flame is needed to initiate the main detonator of the fuze, demolition device, or other device. Since the delay column is purposely kept small in diameter to reduce the volume of gas evolved, thereby permitting smaller delay elements, it may become necessary to include a separate charge or relay. This condition exists particularly with vented delays, since the pressure retained at the terminal end of the time train is greatly reduced. An initiator explosive is usually

used as a relay because (*a*) it does not introduce any appreciable delay and (*b*) it takes flame readily.

The relay charge, which is fastened securely to the delay by a crimp or thread, finds its greatest usefulness in designs where air gaps exist or are likely to exist between the terminal end of the delay and the receiving explosive charge. In cases where variable air gap conditions do not exist or when the air gap is very small with high confinement, the relay detonator is omitted and the main detonator is secured close to the terminal end of the delay.

Fulminate of mercury was formerly used as a relay detonator charge, but has now been almost wholly displaced by lead azide,

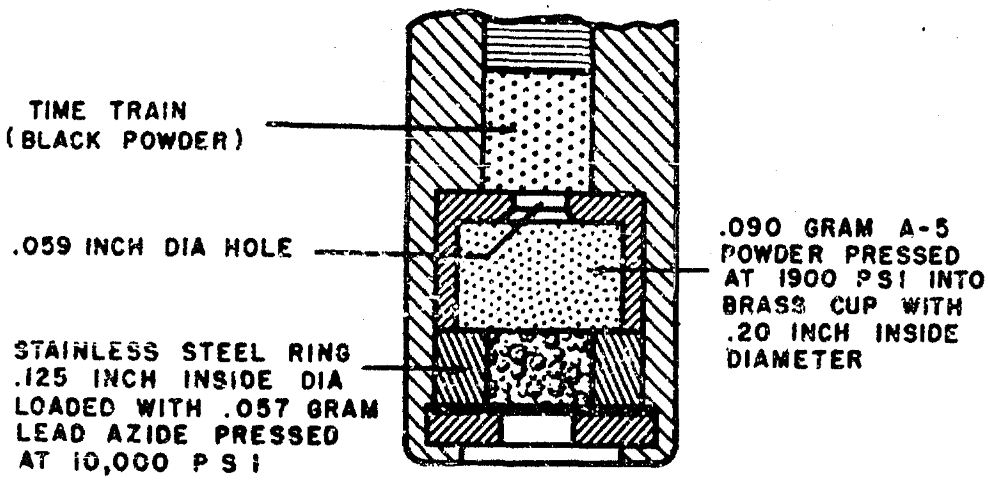

Figure 5–27. A Relay Detonator Design.

which has better surveillance qualities. The lead azide is usually loaded into aluminum cups, since it is incompatible with copper bearing metals.

At assembly in the delay element some means, such as thin paper disks, should be provided to prevent contact between the aluminum and the black powder pellet.

The relay detonator design shown in figure 5–27 has given satisfactory results in 7-second and 7.7-second vented delay elements in the temperature range of −65° F to 160° F. The lightly pressed black powder charge at the terminal end of the vented delay column is provided to produce sufficient heat and pressure to assure reliable initiation of the lead azide detonator. In this design, care must be taken to attain intimate contact between the loosely pressed powder in the cup and the end of the time train.

Design Factors

Size of components. The size of the delay element is determined by empirical methods; however, various factors have in the past served to indicate a range within which these methods are utilized to effect a closer approach to the optimum size.

Diameter of powder column. The elements are kept to a minimum size in order to conserve space, which is usually a critical factor in fuze design. Practice has shown that a 0.1 inch diameter black powder column is the smallest practical size from the standpoints of loading ram strength and flame evolution required to ignite a detonator or relay detonator. As a general practice, a 0.125 diameter column has been standardized to facilitate the loading of the longer delay columns where the stiffness of the ram is critical.

Diameter of delay body. The minimum O. D. of the delay body must be such as to resist swelling under loading pressures and to withstand the internal gas pressure obtained during burning. Since the former pressures are greater, the latter are unimportant in this connection. In general, the O. D. required to resist the loading pressure is less than the diameter of the standard-type primers utilized. Thus the O. D. is usually the minimum which will accommodate the primer and yet be of a standard bar stock diameter.

Length of black powder column. The determination of the length of black powder column required to obtain the desired burning time is a cut-and-try affair. The length can be increased or decreased within limits and the same time still be retained by varying the loading pressure, number of increments, type of powder, or size of expansion chamber. A review of existing designs should enable the designer to estimate the length of the column needed with sufficient accuracy so that with slight adjustments of loading pressure, increment sizes, and expansion chamber, the desired burning time can be obtained.

Size of expansion chamber. In designing the expansion chamber, its diameter is usually made as large as possible without unduly weakening the side walls which support the primer anvil, or such washer or baffle as may be used for that purpose. The depth should be shallow enough to allow proper ignition of the pellet from the primer and enable sufficient build-up in pressure to effect a good spurt of flame as the burning zone reaches the terminal end of the pellet. Too small a chamber must be guarded against since excess pressure will result in undue strain being put on the unsupported center section of the primer cup and blow-through troubles will be probable. The size of the baffle, if one is used, will many times be a determining factor in the expansion chamber depth.

Size of baffle. As noted previously, the size of the baffle is determined primarily by the size of the gas ports. These latter should be as large as is consistent with the necessary structural strength of the component and the requirement that the primer gases be not permitted to impinge directly upon the pellet. In the case of suspended baffles (fig. 5–23), the strength must be sufficient to resist the blast effects of the primer. The strength can be tested by firing samples having inert loaded delay pellets. The diameter of the baffle is controlled by the expansion chamber size, which should be of as great a diameter as is permitted by primer construction.

The sizes of the expansion chambers and baffles are affected by the delay times desired. A short delay, say 0.01 second, uses a very small pellet of questionable structural strength. In order to increase the size (strength) of the pellet and still retain the burning time of 0.01 second, the chamber is kept small and well filled with a large baffle (fig. 5–26). This arrangement increases internal pressure and accelerates the rate of burning. To conserve over-all length when a longer delay time is required, a small baffle is employed to take maximum advantage of the expansion chamber allowing lower pressures which decrease burning rates (fig. 5–26, right).

Size of relay detonators. The size of the relay detonator is not critical from the standpoint of the functioning of the delay element. The strength (power) is dictated by the safety and functioning requirements imposed by the mother device. Convenient sizes from the loading and assembly standpoint are 0.125 inch diameter by 0.10 inch high or 0.160 inch diameter by 0.125 inch high. The latter size is preferable since it has been widely employed and its use tends to promote standardization.

Effects of Variables on Burning Time of Delay Elements

The effects of the following variables on the performance of black powder delay elements have not been thoroughly investigated to date.

(*a*) Effect of Moisture Content of Black Powder.
(*b*) Effect of Type of Powder.
(*c*) Effect of Primer Output.
(*d*) Effect of Volume of Expansion Chamber.
(*e*) Effect of Temperature.
(*f*) Effect of Pressure Dwell.
(*g*) Effect of Loading Pressure.
(*h*) Effect of Size of Increment.

A series of exploratory tests were conducted in the interest of supplying rough answers to these questions. Much work remains to

be done along such lines. The delay elements used in the various tests were the following:

0.010 second Obturated (fig. 5–9, page 5–11).
0.250 second Obturated (fig. 5–10, page 5–12).
0.033 second Obturated (fig. 5–2, page 5–4).
0.070 second Obturated (ref. (5)).
0.004 second Pressure (fig. 5–13, page 5–17).
7.0 seconds Vented (NOL sketch 150185) (ref. (1)).
7.7 seconds Vented (NOL sketch 152156).

Effect of moisture content of black powder. Obturated delay elements having nominal burning times of 0.01, 0.033, and 0.25 second were loaded with black powder of varying moisture content and tested for burning time with and without desiccation.

Tables 5–1 and 5–2 and figures 5–28 and 5–29 show summaries of the results of tests in which black powder of varying moisture content was loaded into 0.01 and 0.25 second delay elements and the burning times determined within 2 hours after loading. Since the burning times were determined shortly after loading, it could be assumed that there was no change in the moisture content of the black powder.

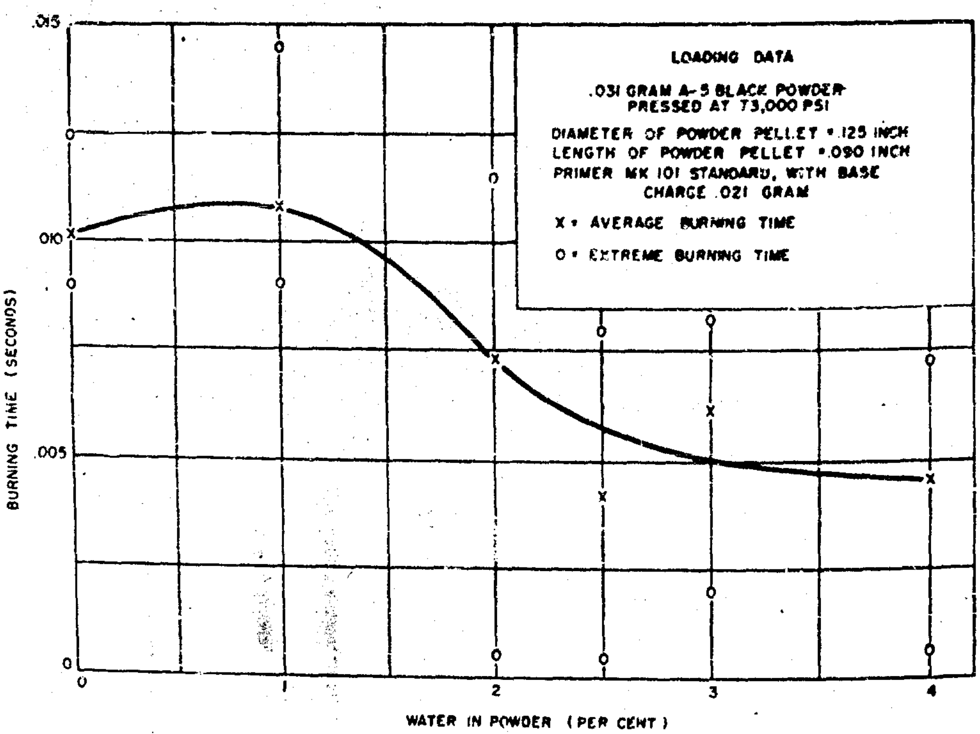

Figure 5–28. Burning Time vs. Moisture, 0.010 Second Obturated Delay Element.

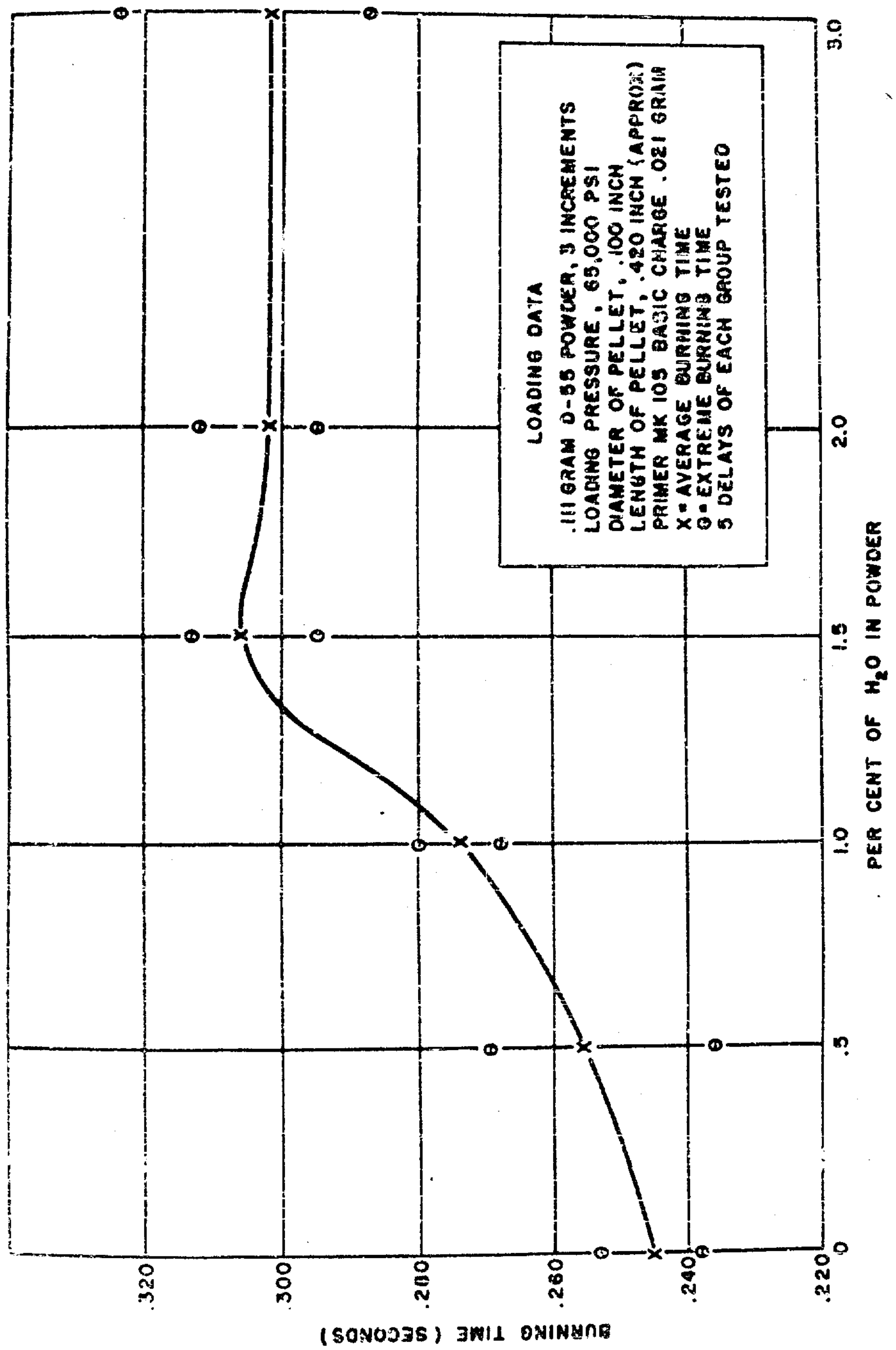

Figure 5–29. Burning Time vs. Moisture, 0.25 ± 0.025 Second Obturated Delay Element.

TABLE 5–1.—*Effect of Moisture Content of Black Powder on Burning Time, 0.010 Second Delay Element (0.081 gram A–5 Powder, 73,000 psi) (Figure 5–9)*

Number tested	Percent of H_2O by weight	Burning time (seconds)		
		Minimum	Maximum	Average
10	0.0	0.0090	0.0124	0.0102
14	1.0	.0050	.0146	.0108
16	2.0	.0005	.0114	.0073
6	2.5	.0005	.0090	.0042
6	3.0	.0020	.0083	.0062
10	4.0	.0007	.0073	.0047

TABLE 5–2.—*Effect of Moisture Content of Black Powder on Burning Time, 0.25 Second Delay Element (0.111 gram D–55 Powder, 65,000 psi.) (Figure 5–10)*

Number tested	Percent of H_2O by weight	Burning time (seconds)		
		Minimum	Maximum	Average
5	0.0	0.233	0.252	0.245
5	.5	.236	.269	.255
5	1.0	.268	.280	.274
5	1.5	.295	.313	.306
5	2.0	.295	.305	.302
5	3.0	.292	.324	.302

For the purpose of observing the effects of desiccation on delays which had been loaded with moist black powder, tests were conducted on three groups of 0.033 second delay elements (shown in figure 5–2) which were loaded with powder originally from the same source but containing different percents of moisture at the time of loading. Of each group of twenty delay elements, ten were stored immediately after loading for a period of time in rubber stoppered glass bottles and the remaining ten were stored for the same period in desiccators containing calcium chloride. All delay elements were loaded with 0.040 gram A–5 powder pressed at 82,000 psi. The results of these tests are presented in table 5–3 and shown graphically in figure 5–30.

TABLE 5–3.—*Effect of Desiccation on the Burning Time of Delay Elements Loaded with Black Powder (Figure 5–2)*

Powder loaded	Treatment of loaded elements	Burning time (seconds) lots of 10 elements		
		Minimum	Maximum	Average
Moisture content 0 percent powder desiccated for approx. 600 hours prior to loading.	Bottled 307 hours Desiccated 307 hours	0.0351 .033	0.0384 .0365	0.0369 .0347
Moisture content 0.6 percent accumulated by exposure to atmosphere of approx. 70 percent R. H. for 16 hours.	Bottled 294 hours Desiccated 294 hours	.0341 .0105	.0475 .0405	.0379 .0222
Moisture content 1.0 percent (artificially added).	Bottled 307 hours Desiccated 307 hours	.0098 .0062	.0392 .0182	.0312 .0113

The results presented in tables 5–1, 5–2, and 5–3 and in figures 5–28, 5–29, and 5–30 indicate that if moist black powder is loaded and tested without desiccation, the effect on the burning time of delays will be hard to predict. In the case of the 0.01 second delay moisture up to about 1 percent appeared to have little effect. High concentration caused a marked decrease in burning time (fig. 5–28). In the case of the 0.25 second delay, moisture in concentration up to 1.5 percent appeared to cause a progressive increase in burning time (fig. 5–29). In the case of the 0.033 second delay, moisture appeared to decrease the burning time slightly at 1 percent, but to have little effect at lower concentrations (fig. 5–30, undesiccated).

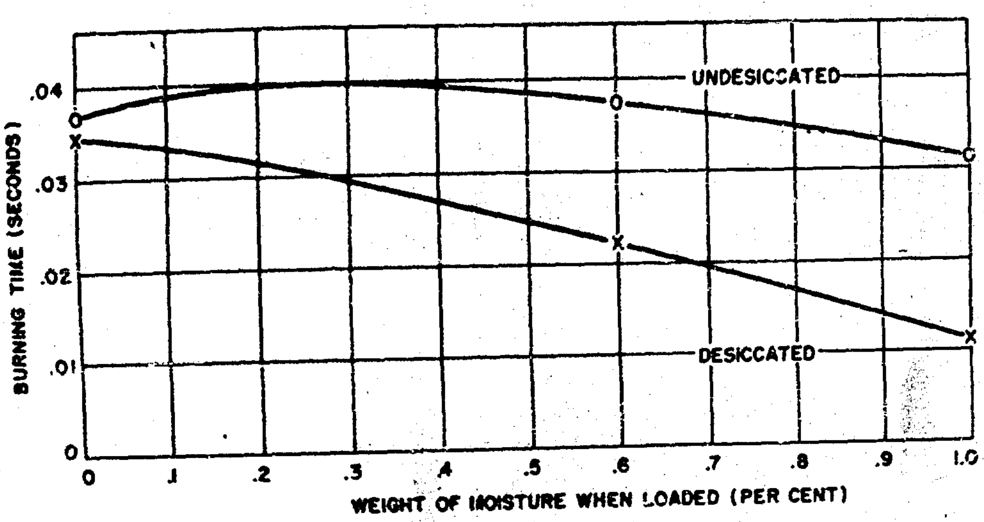

Figure 5–30. Burning Time vs. Moisture With and Without Desiccation, 0.033 Second Obturated Black Powder Delay Element.

In the tests where the powder was loaded wet and then desiccated (table 5–3 and figure 5–30) a marked decrease in burning time was obtained; this decrease was a function of the amount of moisture present in the powder at the time of loading. It is indicated also that desiccation had an effect in lesser degree on delay elements loaded with powder which, for all practical purposes, contained no moisture except such as might have been picked up during the loading operation.

It is concluded that in order to obtain black powder delays of known and reproducible burning times, it is important to load dry powder and to avoid desiccation of the loaded elements.

Under the loading pressures of 65,000 psi and above used in this work, the maximum amount of moisture retained in the pellet is

approximately 2.5 percent, since any excess beyond that amount is squeezed out by the loading ram.

Effect of type of powder. The selection of the proper powder for delay elements depends largely upon the desired burning time. For burning times up to about 0.15 second, Army Grade A-5 powder is commonly used by the Army and Navy. For burning times longer than 0.15 second, it may be necessary (due to limited space) to use a slower burning powder. A powder of this type having the manufacturer's designation D-55 has a considerably slower burning rate than the Army Grade A-5. The difference between fast and slow burning powders is more pronounced in long delays. For example, table 5-4 shows the results of chronograph (burning time) tests of 0.010 second and 0.25 second obturated delays loaded with the two different types of powder just mentioned.

TABLE 5-4.—*Effect of Type of Powder on Delay Time*

Number tested	Delay element	Grade	Powder weight (grams)	Loading pressure (psi)	Burning time (seconds)		
					Low	High	Average
10	[1] 0.010 second	Army A-5	0.031	73,000	0.0060	0.0124	0.0102
5	[1] .010 second	D-55	.031	73,000	.0099	.0110	.0102
5	[2] .250 second	Army A-5	.111	65,000	.144	.160	.151
5	[2] .250 second	D-55	.111	65,000	.238	.253	.245

[1] Figure 5-9.
[2] Figure 5-10.

Table 5-4 shows that the two grades of powder (A-5 and D-55) produced the same over-all results in the 0.010 second delay, whereas the A-5 powder reduced the average burning time of the 0.25 second delay by approximately 39 percent. A description of the various types of black powder will be found on pages 2-19 and 2-20 and in reference (4).

Effect of primer output. Varying primer charge weights tend to produce varying burning times of obturated delays. A light charge tends to lengthen the burning time, while a heavy charge tends to shorten it. The influence of the primer charge is more pronounced in short delays than in long delays. These statements are based on the results of tests conducted on 0.010 second and 0.25 second delay elements using primers with minimum and maximum charges. A summary of the test is given in table 5-5.

TABLE 5-5.—*Effect of Primer Output on Burning Time*

0.25 second delay (fig. 5-10) D-55 powder, 0.111 gram, 65,000 psi. Navy Primer Mk 105 Standard		0.010 second delay (fig. 5-9) A-5 powder, 0.031 gram, 73,000 psi. Navy Primer Mk 101 Standard	
Weight of primer charge (grams)	Burning time average for 10 samples (second)	Weight of primer charge (grams)	Burning time average for 10 samples (second)
0.019 (minimum)	0.238	0.019 (minimum)	0.0106
0.023 (maximum)	.229	0.023 (maximum)	.0091

The delays using primers with minimum charges produced burning times that were approximately 4 percent and 16 percent longer than those with maximum charges in the 0.25 second and the 0.010 second delays, respectively.

Effect of volume of expansion chamber. Variations in the size of the expansion chamber will cause variations in the burning time of a given obturated delay. Figure 5-31 shows the results of tests conducted on a column type obturated delay (0.25 second approx.) using delay bodies with full, three-quarter, one-half, and one-quarter volume expansion chambers, other features being held constant. The basic volume of the expansion chamber for this delay is 0.0114 cu. in. The graph shows that the drop in burning time is not so pronounced until the expansion chamber is below 75 percent of the basic volume. Between 75 and 25 percent of basic volume, the shortening of burning time appears to be a linear function of the volume. It is pointed out that the results shown on the graph are for one specific delay element. The burning time of other delays may not be affected in the same degree. However, the graph illustrates the general trend of burning times as affected by variations in the expansion chamber.

Effect of temperature. Some data on temperature effects are presented on pages 5-22 to 5-24. The data recorded here concerning the effect of temperature on burning times were gained from a series of tests conducted on six different column delays including the obturated, vented and pressure types. A summary of the tests is given in table 5-6. Figures 5-19, 5-20, 5-32, 5-33, and 5-34 show the general trends of burning times at the given temperatures. No graph was made for the 0.07 second delay, as it was not tested at high temperature.

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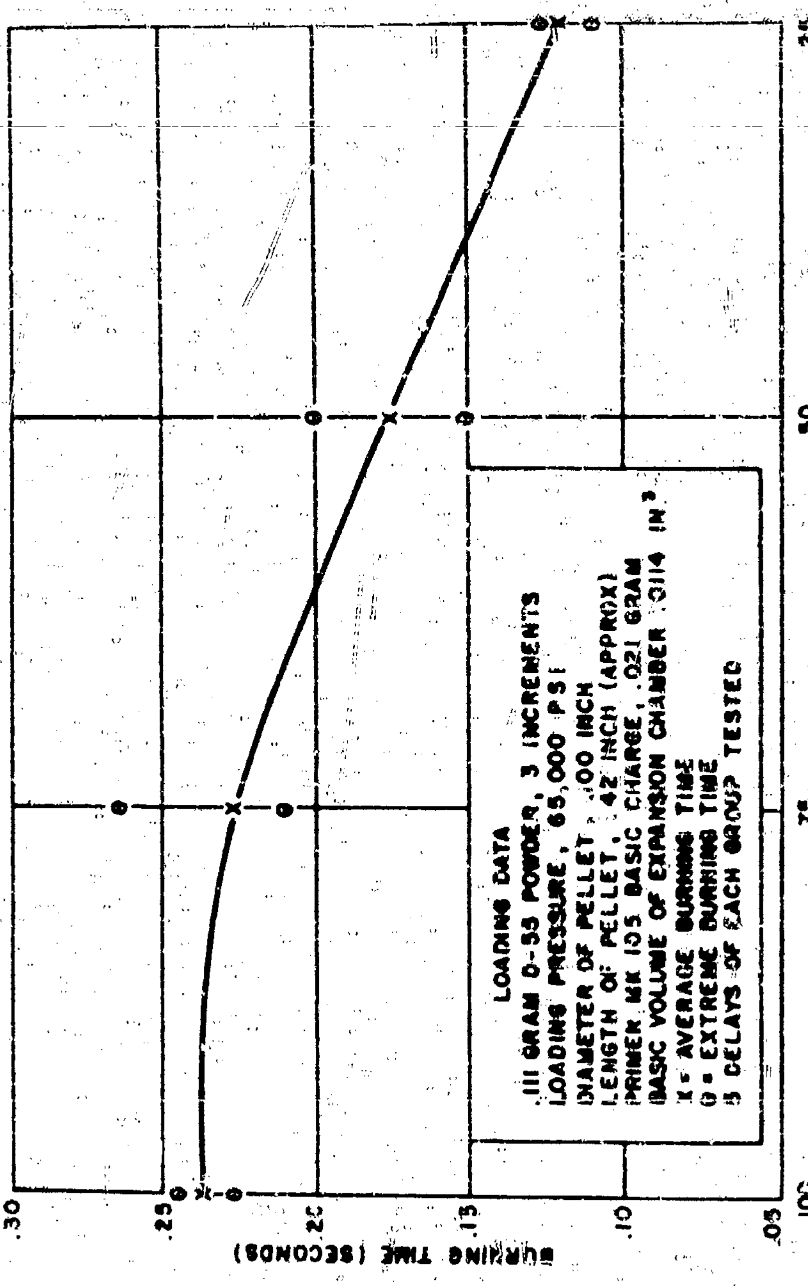


Figure 5-31. Burning Time vs. Volume of Expansion Chamber, 0.25 ± 0.025 Second Obturated Delay Element.

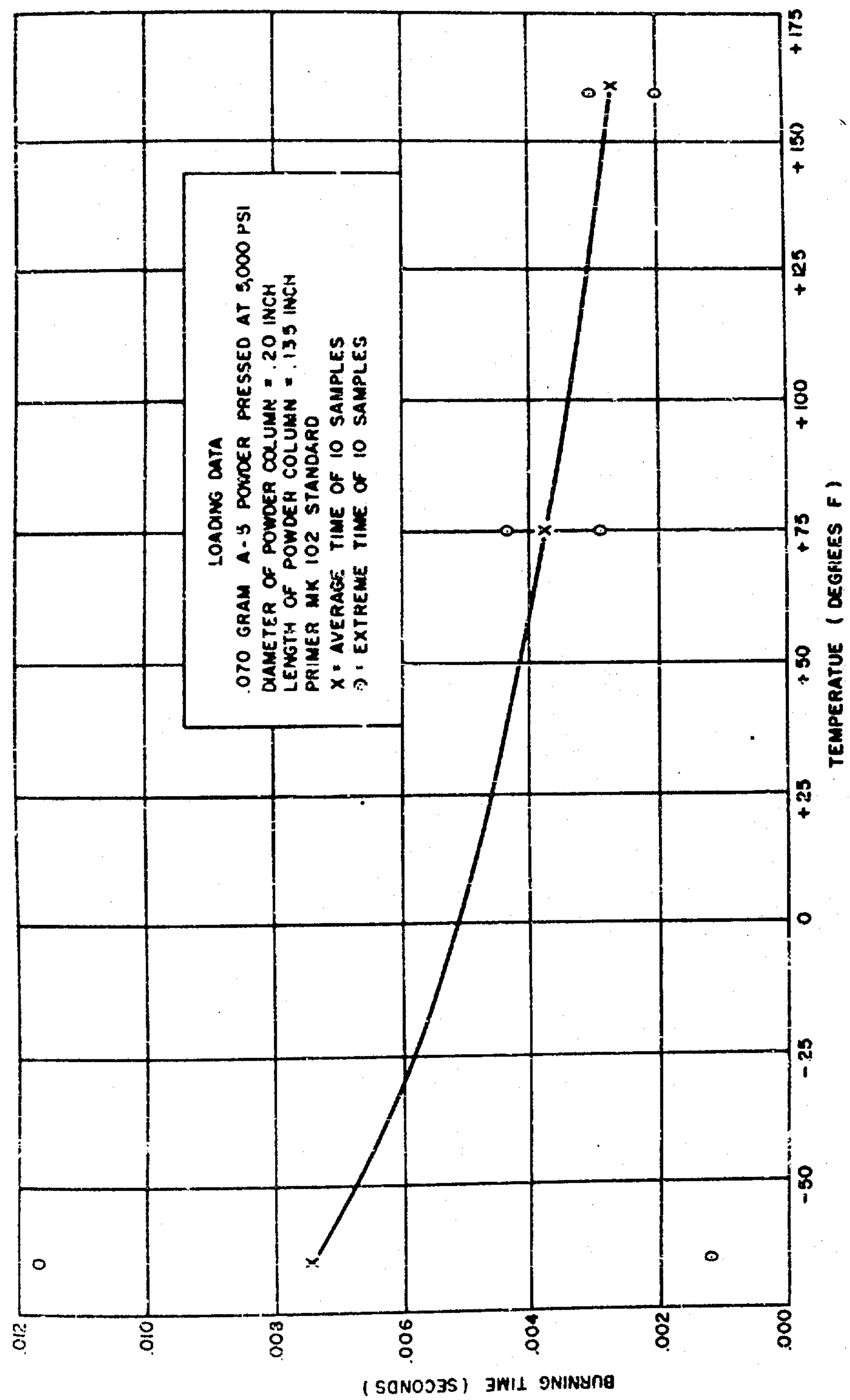


Figure 5-32. *Burning Time vs. Temperature; 0.004 Second Delay Element, Pressure Type.*

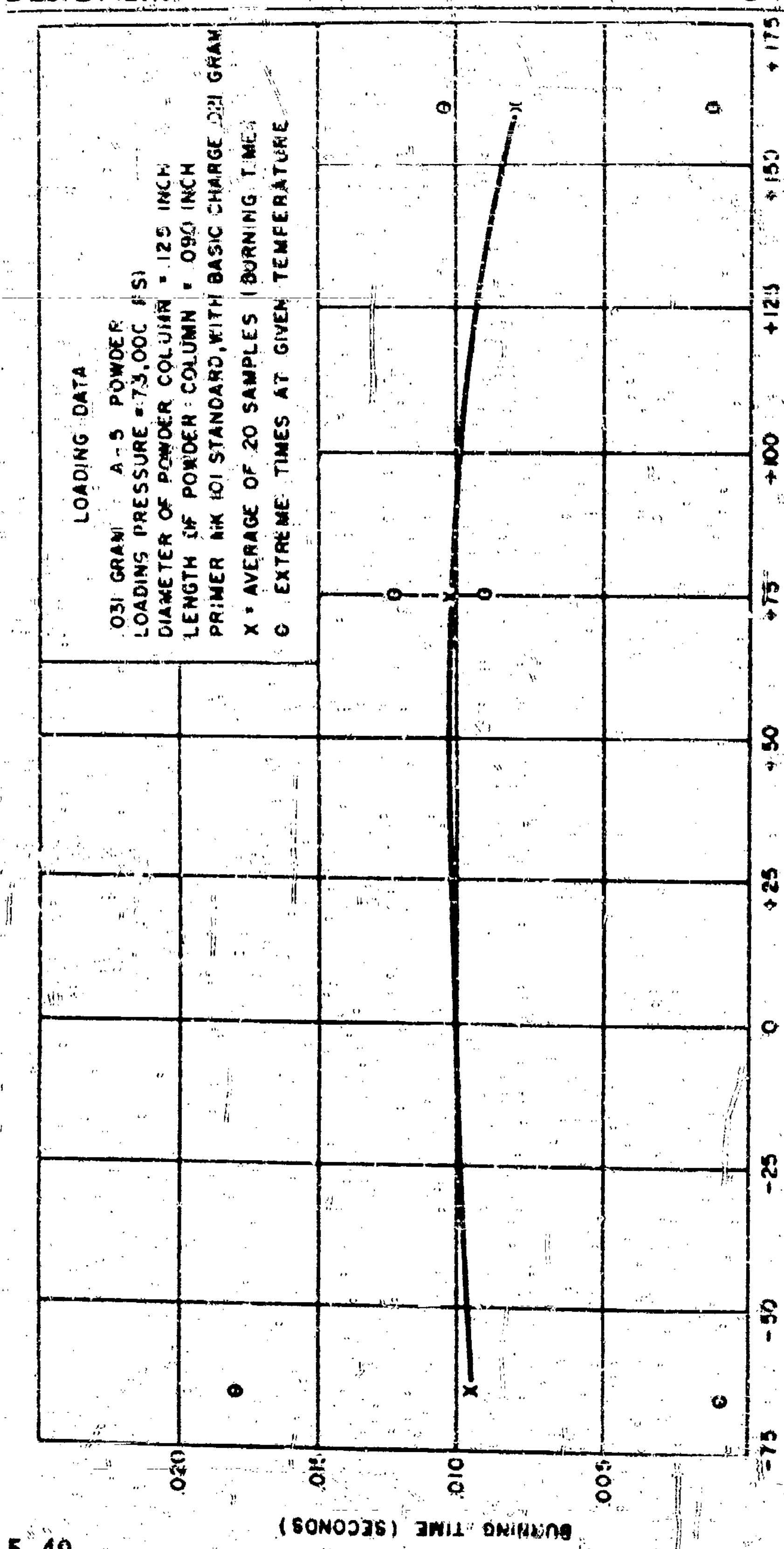


Figure 5-33. Burning Time vs. Temperature; 0.010 Second Delay Element, Obturated.

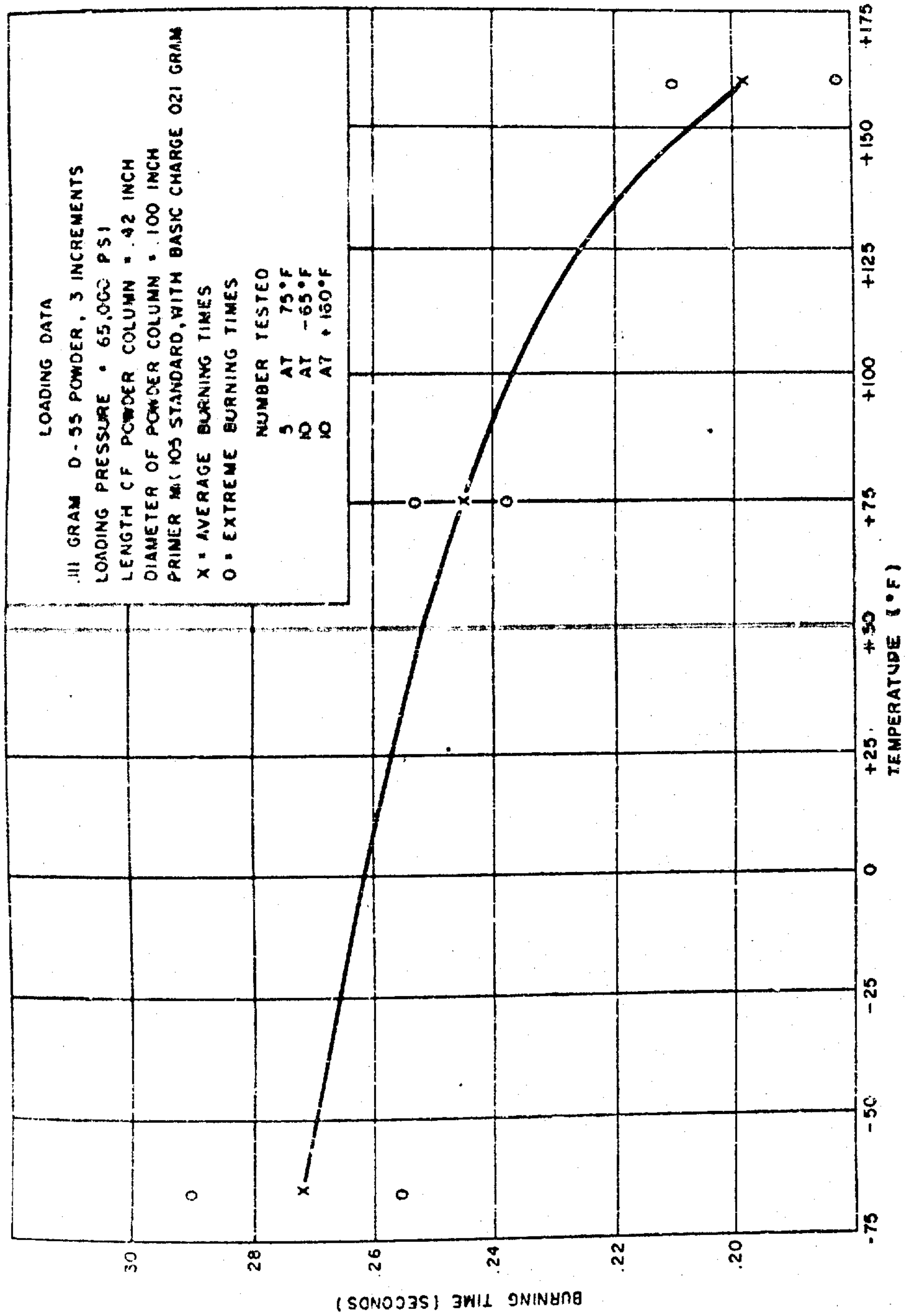


Figure 5-34. Burning Time vs. Temperature, 0.25 Second Delay Element, Obturated.

TABLE 5-6.—*Effect of Temperature on Burning Time*

Type of delay [1]	Number tested	Temperature (° F)	Burning time (seconds)			Effect on time compared to control samples
			Minimum	Maximum	Average	
0.004 second P [2]	10	+75	0.0029	0.0044	0.0038	
	10	−65	.0014	.0117	.0075	Lengthened 100 percent
	10	+160	.0020	.0031	.0027	Shortened 29 percent
0.010 second O [3]	20	+75	.0090	.0124	.0102	
	20	−65	.0010	.0182	.0097	Shortened 5 percent
	20	+160	.0010	.0105	.0081	Shortened 20 percent
0.070 second O [3]	5	+75	.0660	.0765	.0700	
	20	−80	.0620	.0918	.0816	Lengthened 17 percent
Approx. 0.25 second O [3]	5	+75	.238	.253	.245	
	10	−65	.255	.290	.272	Lengthened 11 percent
	10	+160	.182	.210	.198	Shortened 19 percent
Approx. 7.0 second [5] V [4]	5	+75	6.585	6.835	6.728	
	6	−80	5.800	6.760	5.986	Shortened 11 percent
	10	+160	6.625	6.920	6.769	Lengthened 0.4 percent
	10	+75	7.620	7.845	7.736	
7.7	10	−65	7.650	8.160	7.948	Lengthened 2.7 percent
V [4, 6]	10	+160	7.160	7.660	7.485	Shortened 3.3 percent

[1] Delay Elements used in the above tests are identified as follows:
0.004 second, Figure 5-13.
0.010 second, Figure 5-9.
0.070 second, Ref. (5).
0.25 second, Figure 5-10.
7.0 second, NOL Sketch 150185 (Ref. (1)).
7.7 second, NOL Sketch 152156 (Ref. (1)).
[2] P = Pressure type.
[3] O = Obturated type.
[4] V = Vented.
[5] Vent sealed with solder, melting point 240° F.
[6] Vent open.

On the basis of these tests, the following general statements are made:

(*a*) Low temperature decreases the burning rate of the powder, resulting in longer burning times.

(*b*) High temperature increases the burning rate of the powder, resulting in shorter burning time.

(*c*) Vented delays of long burning time are the least affected by temperature.

The results on the 0.010 second and the 7 second delays seem to be at variance with statements (*a*) and (*b*) above. In the case of the 7 second delay, the vent hole being solder sealed caused it to act as an obturated delay until the solder was expelled. It is reasoned that the low temperature delayed the expulsion of the solder, allowing internal pressure to build up, thus increasing the burning rate. The high temperature quickened the expulsion of the solder, thus eliminating or reducing the initial internal pressure which would ordinarily be present when tested at ambient temperature.

The reason for the seeming discrepancy in the data on the 0.010 second delay is that the average burning time was reduced by several very short delay times. The cause of extremely short burning times of 0.010 second obturated delays when tested at low temperatures has not been determined. It is believed that the low temperature

has a weakening effect upon the web of the powder pellet (see fig. 5–35). Several tests have been conducted to determine whether the pellet was fractured or otherwise permanently affected by the low temperature. These tests were made by chilling the delay assemblies to −65° for a period of several hours, then testing them after they had been allowed to warm up to ambient temperature. The results indicated that the powder pellets were not permanently damaged, since all of them produced normal burning times when tested.

Effect of pressure dwell. In press loading of explosives and pyrotechnics, the rate of application of pressure may have an effect on performance and in some cases it may be desirable to determine the maximum permissible rate of application. For experimental loading, a low rate of pressure application is used. After ~~the maximum~~

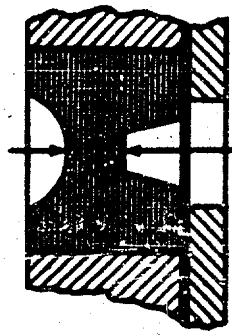


Figure 5–35. Web of 0.010 Second Delay Pellet.

pressure has been attained, an interval of continuous pressure, or dwell, is sometimes desirable to ensure proper consolidation of the powder grains. The relatively good flow of black powder plus the smooth surface conditions required of loading tools and delay pellet bores indicate that little if any dwell is actually needed in the consolidation of this material. However, plant practice is to stipulate a short dwell (1 to 3 seconds approximately) as a control of the workman to insure his applying full loading pressure. Experimentally, it may be found that as the l/d ratio of each increment is increased, a minimum dwell may have other and more pertinent beneficial effects. Tests conducted on 0.010 second and 0.25 second column delay elements, using 1, 2, 3, 6, and 10 second dwell intervals, produced results which although not conclusive indicate that a dwell interval of one second is sufficient for a powder column having a l/d ratio of 0.72 or less. Table 5–7 is a summary of these tests. Five elements were used for each group. Although these data can well serve as a general rule, it is deemed advisable to conduct tests on newly developed designs to determine whether a dwell is necessary.

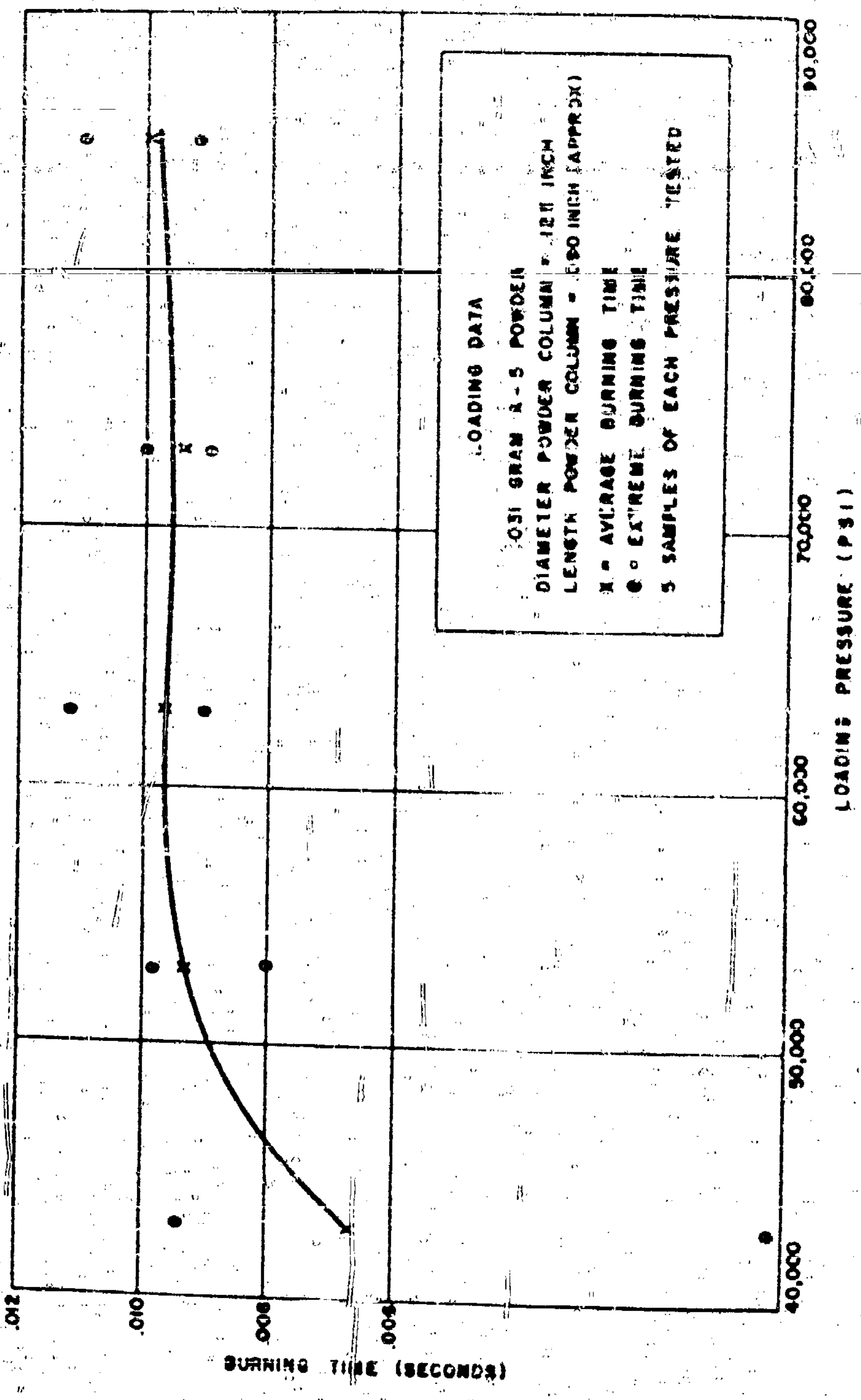


Figure 5–36. Loading Pressure vs. Burning Time, 0.010 ± 0.003 – 0.004 Second Obturated Delay Element.

TABLE 5-7.—*Effects of Varying Pressure Dwell*

0.25 second delay (fig. 5-10)	Burning times for dwell of—		
	3 seconds	6 seconds	10 seconds
Minimum	0.221	0.199	0.234
Maximum	.251	.244	.244
Average	.234	[illegible]	.239

0.010 second delay (fig. 5-9) A-5 powder, 0.031 gram, 73,000 psi Pellet length, 0.090 inch; dia. 0.125 inch	Burning times for dwell of—				
	1 second	2 seconds	3 seconds	6 seconds	10 seconds
Minimum	0.0097	0.0098	0.0100	0.0099	0.0092
Maximum	.0112	.0109	.0147	.0106	.0118
Average	.0105	.0104	.0113	.0101	.0102

Effect of loading pressure. Within certain limits, the burning time of delay elements is affected by the loading pressure of the powder. For the purpose of observing this effect, tests were conducted on two obturated delays (0.010 second and 0.25 second), using various loading pressures. Figures 5-36 and 5-37 show the trend of burning times for these delays at the given loading pressures. The results of the tests indicate that for obturated column delays the burning time increases continuously with increasing loading pressure until a pressure of about 60,000 psi is reached. Additional pressure has little if any effect upon the burning time. It should be said, however, that

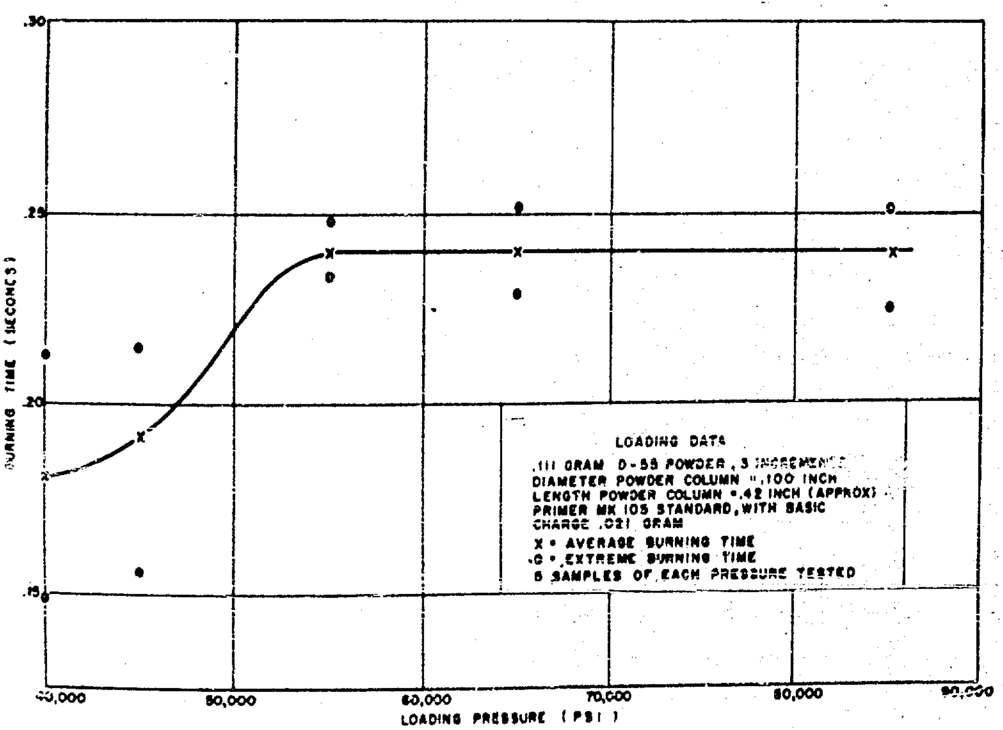


Figure 5-37. Loading Pressure vs. Burning Time, 0.25 ±0.025 Second Obturated Delay Element.

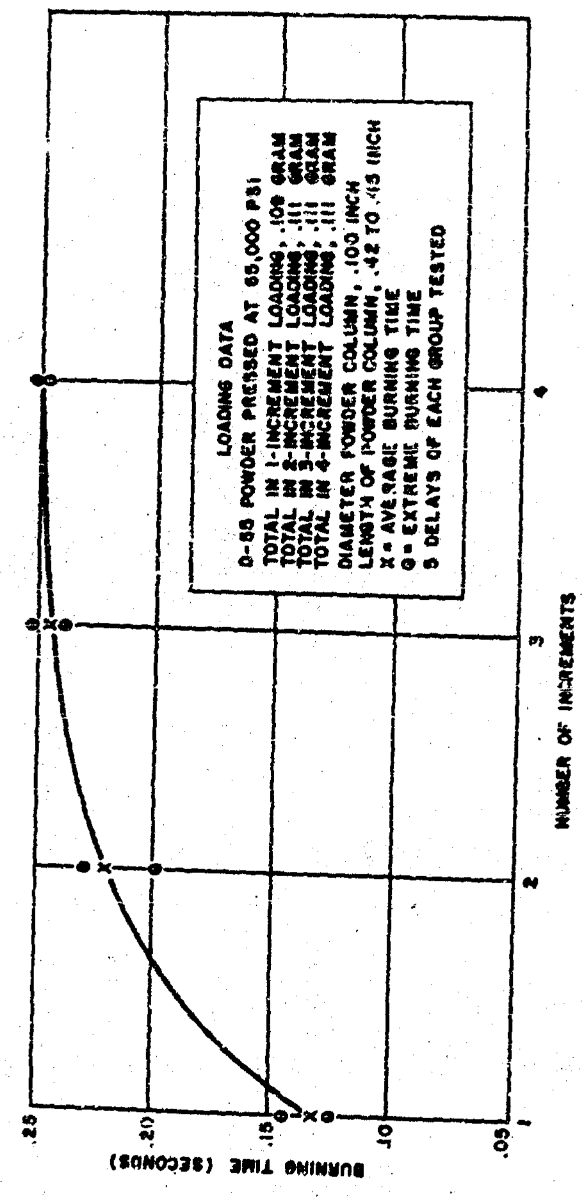


Figure 5–38. Burning Time vs. Single and Multiple Increment Loading; 0.25 Second Obturated Delay Element.

there are other factors such as impact conditions to be considered in the design of a delay pellet, which may make it desirable or necessary to use higher loading pressures. In the case of the pressure type delay shown in figure 5–13, the maximum permissible loading pressure is about 7,000 psi. A loading pressure of 10,000 psi has produced failures in 4 of 5 tests of this delay element (ref. (2)).

Effect of size of increment. Long powder columns are loaded with multiple increments for the purpose of attaining a satisfactorily uniform density. Unless this is done, short and/or erratic burning times will result. Figure 5–38 shows the trend of burning times of a 0.25 second delay loaded with one, two, three, and four increments. The length of the powder column of this delay is normally 0.42 inch approx., the pellet cavity being about 0.45 inch long. It was necessary to decrease the powder charge in the one-increment loaded delays to 0.109 gram, as the full charge of 0.111 gram could not be pressed in one operation. Referring to the graph, it is noted that in the group loaded with four increments, the spread between the maximum and minimum burning times was 0.005 second; the ratio of increment length to diameter was $1/d=1.05$. The next best results were obtained from the three-increment loaded group where the spread was 0.015 second, the ratio of the increment being $1/d=1.40$. This test is considered a good example of the effectiveness of multiple increment loading of long column delay elements.

Section 2.—Gasless Delay Elements

The problem of handling the gases produced by the burning of conventional delays is often a difficult one for the fuze designer, since pressure affects the burning rate of such materials. This problem is much less serious in the case of gasless delays, because the amount of gas produced is small and the burning rate is less sensitive to pressure. This superiority of gasless delays is much more apparent in the case of the longer delay times, and hence they have been more widely applied where the required delay is one second or more.

Gasless delay assemblies fall into two general types, obturated and non-obturated. The choice of type usually depends upon the method of initiation. For example, the non-obturated delay may be ignited by a black powder flash, as from an ejection charge; the seal on the obturated delay prevents such initiation, and it must be ignited by an electric or percussion primer which, in turn, is actuated by electrical or mechanical energy. The obturated delay element assembly possesses the advantage that it may be more readily sealed against adverse atmospheric influence.

Obturated Delay Element Assemblies

ND-59 Electric delay fuze Primers Mk 115, 116 and 117. The general arrangement for Primer Mk 115 is shown in figure 5-39 (BuOrd drawing B-398666). Primers Mk 116 and 117 are as shown in figure 5-39, except that they have longer delay columns. The burning times of these delays are 0.25, 0.50, and 1.0 seconds, respectively. Instantaneous primers of this type are also made, and in both the instantaneous and delay primers, the proper electrical sensitivity is obtained by surrounding the bridge wires with XC-9 priming mixture. (See page 2-10.)

In each case, the base charge consists of a dry mixture of 75 percent DDNP and 25 percent potassium chlorate. However, the delay primers use an ignition charge consisting of 71 percent lead, 27 percent

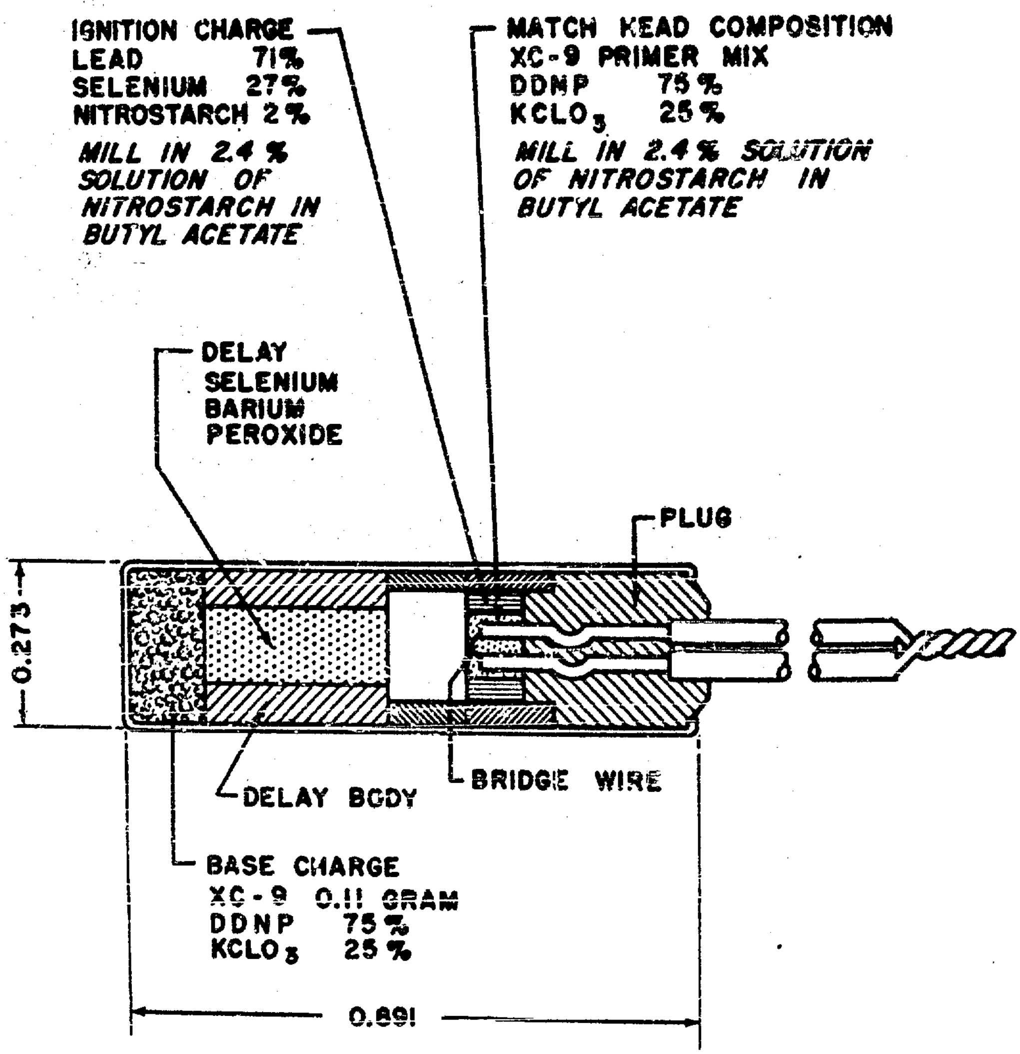


Figure 5-39. Electric Delay Fuze Primer Mk 115, General Arrangement.

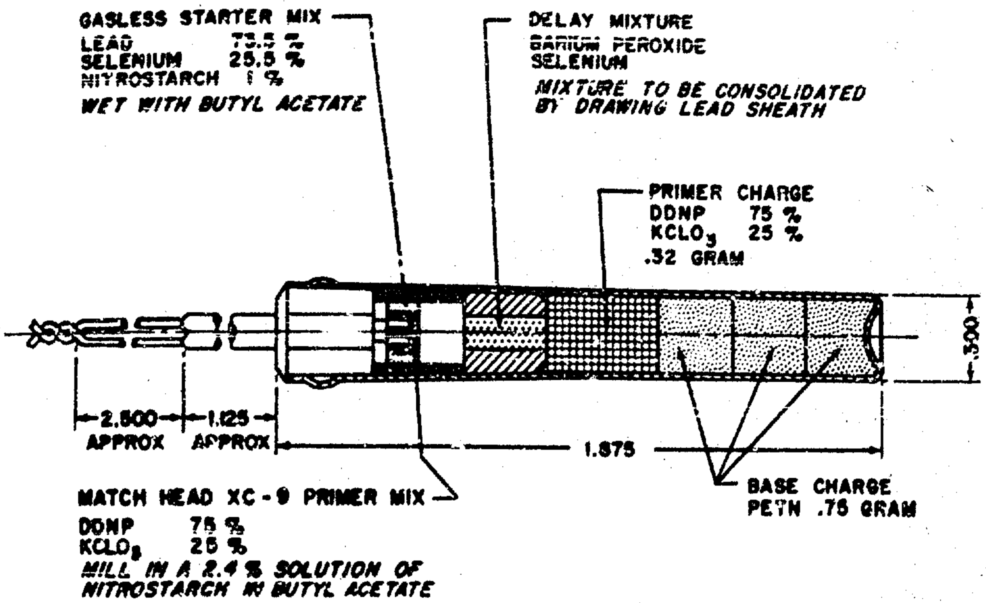


Figure 5–40. Electric Delay Detonator Mk 35 Mod 1. General Arrangement.

selenium, and 2 percent nitrostarch directly over the XC–9 on the bridge wire. This charge, which produces a hot flame with very little brisance, is designed to ignite the delay column without causing disruption which might lead to erratic burning times. The delay column, which is between the ignition charge and the base charge, is composed of barium peroxide and selenium. This mixture is loaded into a lead sheath and consolidated by drawing the sheath down to a specified size after loading. The characteristics of the barium peroxide/selenium mixture are discussed on page 2–18.

Electric Delay Detonator Mk 35 Mod 1. The main characteristic of this device which distinguishes it from the Primer Mk 115 (fig. 5–39) is its explosive power due to the addition of PETN to the base charge. As shown in figure 5–40 (BuOrd Drawing 398199), the construction of this electric detonator is very similar to that of the Primer Mk 115.

Experimental percussion delay detonator. An experimental obturated percussion delay detonator is shown in figure 5–41. The delay body is loaded before the detonator is crimped in place or the primer assembly is screwed into the body. The detonator cup containing the lead azide is loaded before assembly. The seal is provided at one end by the crimp over a soft thin metal sealing disk and at the other end by the shoulder of the primer holder bearing on the primer flange and the soft metal primer washer.

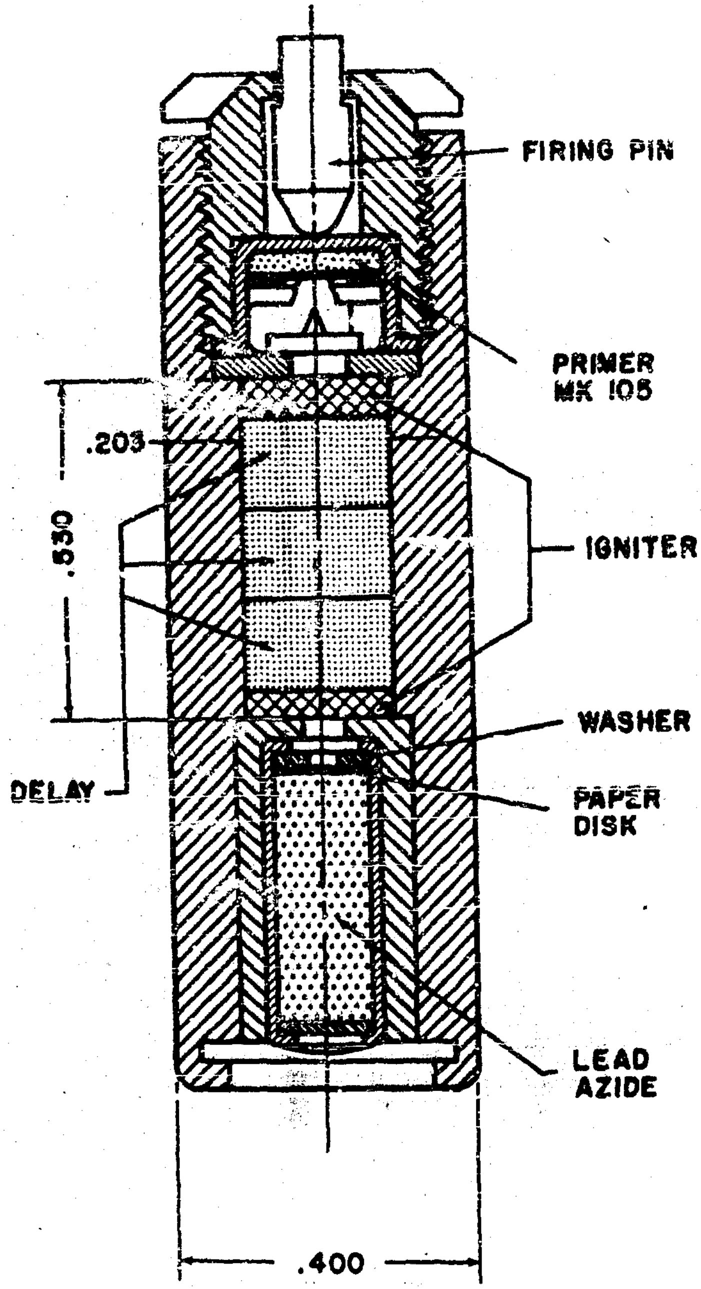


Figure 5–41. Four to Six Second Experimental Obturated Percussion Delay Detonator.

Sufficient igniter to provide thirty or more calories on ignition is loaded into each end of the delay space to transfer ignition to and from the delay. Investigations have shown that the primer is the direct cause of burning time dispersions as high as 1.5 seconds in a 4 second delay.

Non-Obturated Gasless Delay Element Assemblies

A typical non-obturated delay is shown in figure 5–42. It was designed to provide a 4-second delay between two black powder expulsion charges in an illuminating projectile. The first black powder charge initiates the igniter in the 0.1 inch diameter opening; when the delay has burned, the black powder in the delay cavity flashes through the ignition transfer holes to ignite the second expulsion charge. The delay body must be loaded before assembly, and it is important that the black powder be loaded flush with the end of the delay body. If this is done, the delay mixture is held firmly in place when the delay body is screwed tight into the holder. In cases where loaded black powder is pressed against metal, as shown in figure 5–42, it is considered good practice to insert a thin paper disk between the powder and metal to serve as a cushion and thus to minimize the possibility of initiating the powder by friction. Any void below the black powder increases the possibility of the collapse of the loaded mixture due to set-back or expulsion forces.

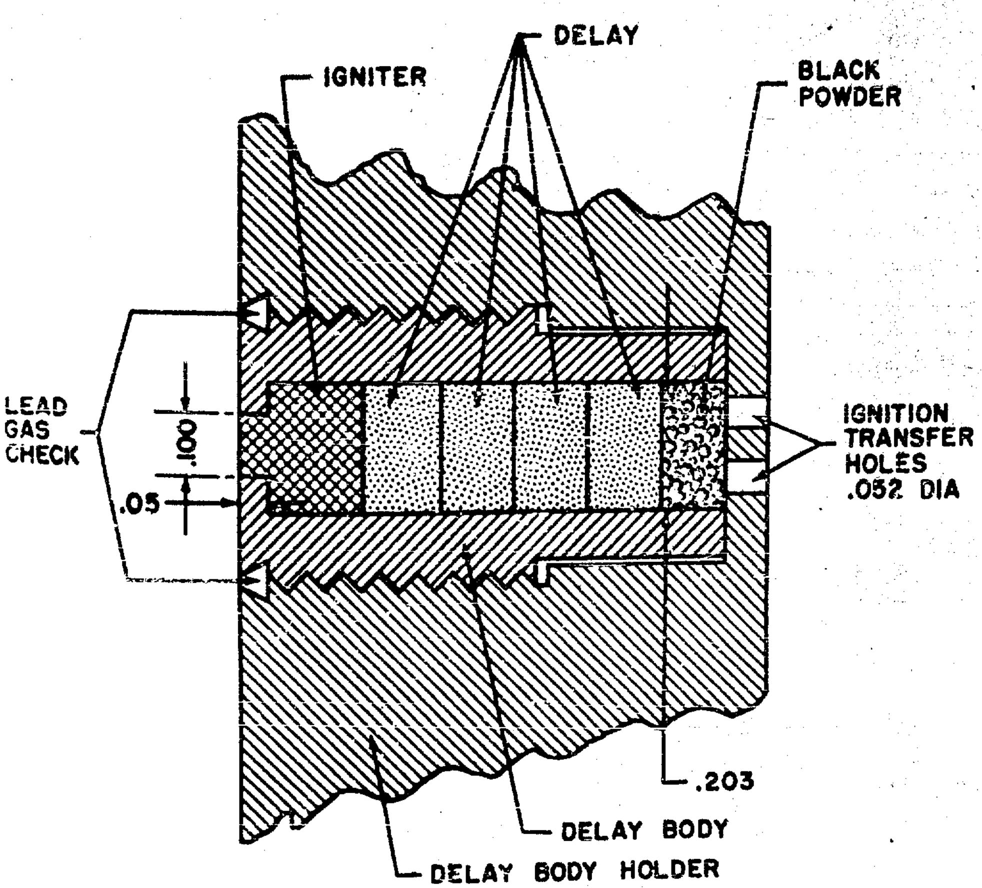


Figure 5–42. Typical 4–5 Second Non-Obturated Delay.

The ignition transfer holes are kept small and out of line with the 0. inch diameter initiation opening for the same reason. In the particular use mentioned above, the first black powder charge forms gases at high pressure and temperature during the expulsion period, and a lead ring is pressed into the gas check opening to prevent these gases from leaking down the outside of the delay body and igniting the secondary expulsion charge.

Design of Gasless Delay Elements

The designer is usually confronted with a situation where he is required to design a gasless delay element having a certain burning time to fit into a given space and to be initiated in a specified manner. To meet these requirements, the two principal variables available are the burning rate of the delay powder and the design of the delay column.

Burning Rate of Gasless Delay Powder

Burning times of delay elements loaded with several different types of gasless delay powders and igniters (refs. (8) and (12)) are presented in Table 5–8. The burning rates of gasless powders are usually not greatly affected by the length of the column, so that the column length required for a given delay time with these powders can be approximated from the data in this table. It is pointed out that rather wide variations in burning rate (ref. (8)) can be achieved by varying the relative amounts of the constituents of the mixture. In general, however, it has been found that mixtures burning slower than about 0.08 inch per second (12½ seconds per inch) tend to be unreliable at low temperatures.

The burning rates of gasless delay mixtures depend on the subsieve size distribution of the powdered metallic fuels as well as the proportions of the ingredients of the mixtures (ref. (9)). Metal powders with a definite size distribution cannot be purchased; and small changes in this distribution result in variations in the burning rate of mixtures in which they are used. Generally, delay mixtures are manufactured by making the mixture in the approximate burning rate range and remixing with added portions of one or more of the ingredients until the desired burning rate is obtained (ref. (10)). In the manufacture of a D–5 manganese delay mixture, a close burning rate control can be established by specifying the limits of particle size distribution in order to limit the range of possible burning rate variation and by adjusting the proportions of the mixture to obtain the desired burning rate. The proportions used are based on the burning

TABLE 5-8.—*Burning Time of Delay Materials Loaded at 35,000 psi into Cold Rolled Steel Bodies Having an Inside Diameter of 0.203 Inch*

Name of mixture	Normal use	Components	Composition (percent)	Weight of mixture	Total length of column occupied by mixture (inches)	Total burning time	Burning time (sec/in.)	Igniter	Method of ignition
HP-25	Delay	Zr $KClO_4$ Ni $BaCrO_4$	5.0 7.5 17.0 70.5	3 increments 0.280 gram each.	0.43	4 seconds	9.3	0.070 gram of F33B or Z-3.	Obturated primer. Mk 105.
				3 increments 0.280 gram each.	0.43	5.3 seconds	12.3		Non-obturated. Black powder, flash.
				5 increments 0.385 gram each.	1.0	11.6 seconds	11.6		Non-obturated. Black powder, flash.
D-5	Delay	Mn $BaCrO_4$ $PbCrO_4$	(1)	Variable	Variable	Variable	2.8 to 12.5 (3)	F33B	Variable.
Z-3	Igniter	Zr $BaCrO_4$	25.0 75.0	1 increment 0.070 gram.	0.052	5-40 (2) milliseconds		None	Obturated primer. Mk 105.
F33B	Igniter	Zr Fe_2O_3 Superfloss (SiO_2)	41.0 49.0 10.0	1 increment 0.070	0.052	0.10 second		None	Non-obturated. Black powder, flash.
				170 mg	0.10	0.15 second	1.75	None	Non-obturated. Electric primer.
6-6-8	Igniter	Si PbO_2 CuO	40.0 30.0 30.0		0.052	0.10 second		None	Non-obturated. Black powder, flash.
						1-20 (2) milliseconds		None	Obturated primer. Mk 105.

[1] Variable according to delay time desired.
[2] Obturated delays burn about 30 percent faster than those that are non-obturated depending on the pressure inside the body during the burning.
[3] Erratic burning times.

rate of a small pilot mixture. With these precautions, the average burning time can be held within about ±3 percent of the desired quantity. If a closer control is necessary, the final adjustment can be made by changing the ratio of the lengths of igniter to delay mixture in the loaded delay element for each batch of delay mixture.

The burning rate of the manganese mixture appears to be slowed down by contact with air of high relative humidity. Although no failures have been noted which can be attributed to this effect, it is probable that condensation of moisture on the delay mixture due to temperature changes at high relative humidity may be sufficient in extreme cases to cause failures. It appears that control of humidity during manufacture, shipping, loading, and testing of the mixtures will result in closer burning time control of the completed delay elements.

The Design of the Delay Column

In designing the delay column, the variables that must be considered are obturation, column length, column diameter, wall thickness and conductivity of the delay body, loading pressure, and loading increment size (ref. (11)).

It is usually preferable to have burning gasless delays open to the atmosphere, since obturation tends to increase the burning rate in a manner that is not always predictable or reproducible (refs. (13) and (14)). This increased burning rate results from pressure built up inside the obturated delay body. The pressure is due to burnt primer gases and to a lesser extent to the small amount of gases given off by the burning delay and igniter powders. If obturation is required for any reason, every effort should be made to keep pressures at a minimum by providing maximum free space and using a minimum of gas producing explosives for igniting the delay column.

The column length required for a given delay time will depend largely on the burning rate of the powder used. If the resulting length exceeds the available space, it is permissible to have the column double back on itself.

The diameter of the delay column (ref. (11)) may be varied within fairly wide limits, although a diameter of 0.203 inch has been widely used. The available data indicate that for thick walled delay bodies the diameter of the column has no appreciable effect on the burning rate, except that the powder will not burn at all if the column is too small. The minimum diameter for successful burning is smaller for the faster burning powders and larger for lower temperatures. These effects are illustrated by the following data obtained on D-5 manganese powder in a thick walled steel body.

TABLE 5-9.—*Effect of Diameter of Delay Column on Burning Characteristics*

Burning time (seconds/inch)	Burning rate (inches/second)	Delay body diameter (inches I. D.)	Successful burning at—	
			Room temp.	−65° F.
3.00	0.33	0.203	Yes	Yes
2.80	.36	.156	Yes	Yes
2.50	.40	.125	Yes	Yes
2.80	.36	.109	Yes	Yes
8.60	.116	.203	Yes	Yes
8.80	.114	.156	Yes	Yes
9.10	.110	.125	Yes	No
....	....	.109	Yes	No
10.90	.092	.203	Yes	Yes
11.00	.091	.156	Yes	Yes
....	....	.125	No	No
....	....	.109	No	No
12.40	.081	.203	Yes	Yes
....	....	.156	Yes	No
....	....	.125	No	No
....	....	.109	No	No

The effect of the wall thickness and the heat conductivity of the wall material on the burning rate of gasless delays has not been thoroughly investigated. Present indications are that this effect varies with the quantity of delay powder, the total burning time, and the heat capacity and conductivity of the delay body. It should be noted that the effective heat capacity of the delay body may be changed by its contact with other metal in a complete ordnance device. Present indications are that if a thick walled body is used, the conductivity is unimportant in the 1–10 second per inch burning time range. However, a thin walled highly conductive body may tend to accelerate the burning rate in the same range of total burning times.

Loading pressures of gasless delay powders may be varied widely, although fairly high pressures are required if the delay is to be subjected to high accelerations. It has been found that consolidation pressures of 30,000 psi are sufficient to enable the D–5 manganese delay mixture to withstand impact forces as great as those encountered by A. P. projectiles passing through armor plate, provided the delay and igniter column is suitably confined by a washer at each end of the column (ref. (12)). Variations of plus or minus several thousand psi in the loading pressure have no noticeable effect on the burning rate.

Variations in increment size in a 0.203 inch diameter body between 200 and 700 mg. do not affect the burning rate. Above this upper limit, the mixture does not consolidate well and the rate tends to decrease. No tests have been run below the lower limit.

The minimum quantity of igniter necessary to ignite the manganese delay mixture loaded in 0.203 inch diameter bodies has been found to be about 50 mg. (ref. (11)). Larger quantities of igniter

tend to increase the burning rate of the initial increment of non-obturated delay mixtures. This acceleration is magnified in obturated delays.

Section 3.—Other Delay Elements

A number of other delay materials have been used experimentally in the electric delay primer whose general arrangement is shown in figure 5–43. The delay case is made of stainless steel and is crimped over a bridge wire type electric initiator. The initiating charge consists of 5 milligrams of normal lead styphnate loaded around the bridge wire. The structure is the same as that in the instantaneous types discussed in section 3 of chapter 3, except that the delay train is interposed between the flash and base charges. A delay spacer, 0.155 inch long followed by a 4-hole delay washer and a further space of 0.050 inch between the washer and the surface of the delay, prevents the explosion of the lead styphnate from disrupting the delay pellet. Initiation of the delay is aided by a cone-shaped depression in the face of the pressed delay next to the initiating charge. The "step" in the line of demarkation between the delay and the base charge aids in ignition transfer as well as in the loading procedure.

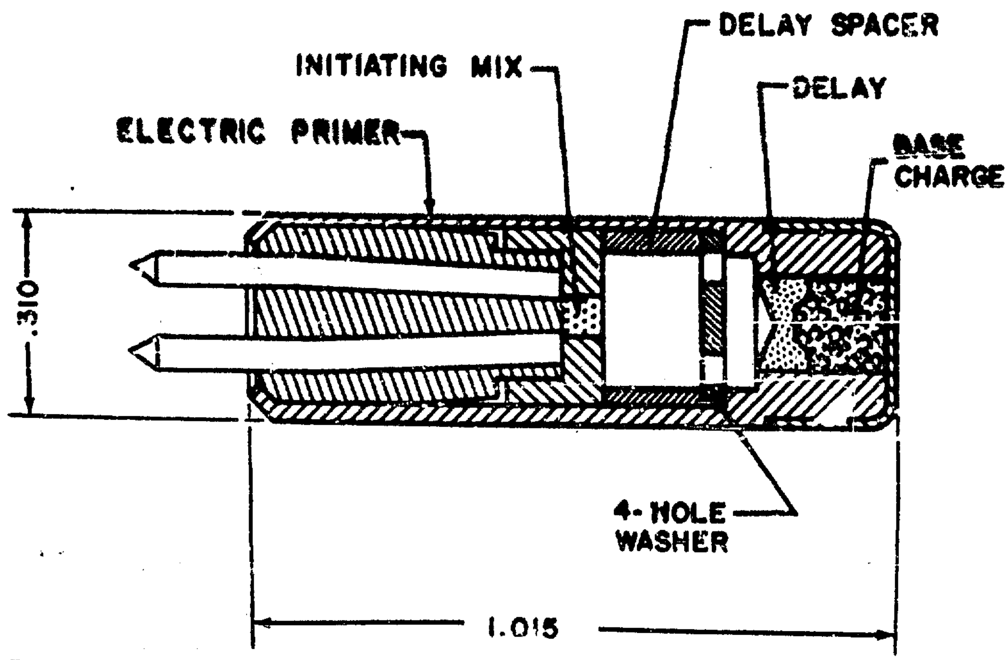


Figure 5–43. Experimental Electric Delay Primer. General Arrangement.

Millisecond Lead Styphnate Delay

The delay column for this delay time is ⅟₁₆ inch in diameter and approximately 0.075 inch long. Freshly prepared lead styphnate, 10.4 milligrams, is dead pressed in this space at 80,000 psi. The freshly prepared delays have consistent burning rates, but this consistency disappears upon long exposure to heat and moisture. This topic is discussed on page 2–23 under the heading Other Materials Used in Short Delays.

250 Millisecond Nitrostarch Delay

A 6.8 milligram delay charge is loaded into a ⅟₁₆-inch diameter cavity with 1 milligram of A–5 black powder added as a starter. The burning time of this delay has not been consistent, and experiments are under way to determine the feasibility of using a gasless mixture in place of the nitrostarch.

Section 4.—Integral Delay Primers and Detonators

It is possible to enclose a complete delay assembly within a single case. As examples of this type of construction, figure 5–44 shows the general arrangement of a flame initiated 0.10 second flash delay

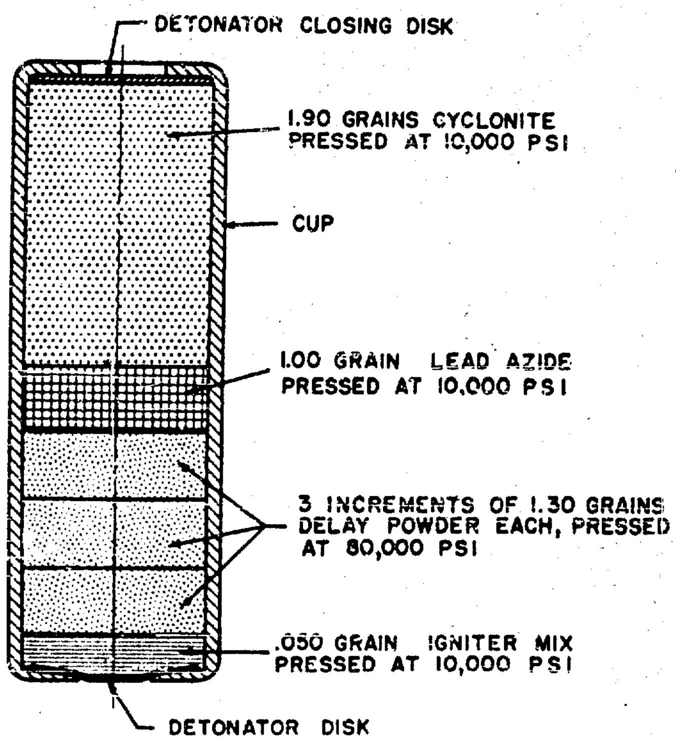
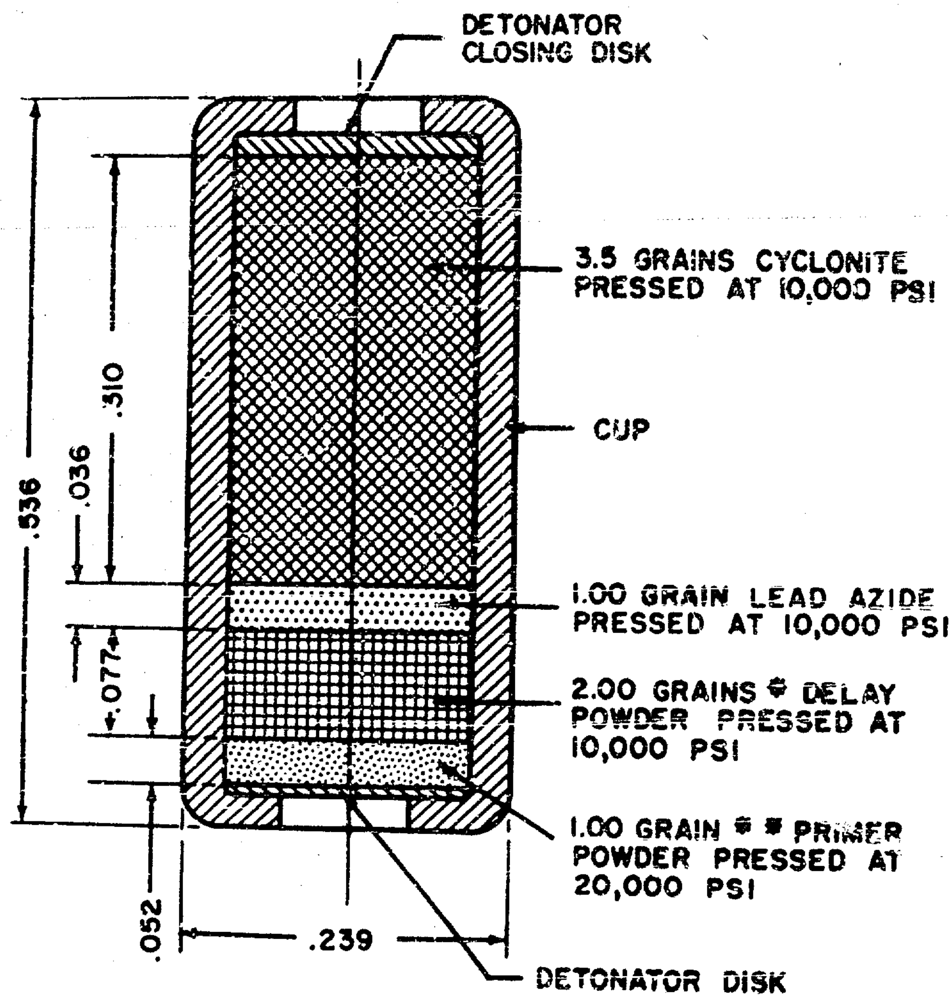


Figure 5–44. Flame Initiated 0.10 Second Flash Delay Detonator. General Arrangement.

detonator, and figure 5–45 shows the general arrangement of a stab initiated 0.02 second delay detonator. These detonators, being developed under Army auspices (ref. (6)), are still in the experimental stage and are not entirely satisfactory from the standpoint of surveillance characteristics, shock resistance, and uniformity.



* DELAY POWDER CONSISTS OF
ZIRCONIUM 55 %
BARIUM CHROMATE 45 %

* * PRIMER POWDER CONSISTS OF
NORMAL LEAD STYPHNATE 15 %
BASIC LEAD STYPHNATE 10 %
TETRACENE 5 %
ANTIMONY SULFIDE 15 %
ALUMINUM 10 %
BARIUM NITRATE 45 %

Figure 5–45. Stab Initiated 0.02 Second Delay Detonator. General Arrangement.

Another device that might be considered a variation of the integral delay utilizes a throttling baffle between the primer and detonator to delay the initiation of the latter (ref. (7)).

Section 5.—References

Parenthetical numbers preceded by the letter "S" are Naval Ordnance Laboratory file numbers.

(1) NOLM 9923, **Black Powder Delay Element for Aircraft Rocket Flare Fuze**, October 6, 1948.

(2) NOLM 10270, **Delay Element XF–1J for Anti-Submarine Rocket Fuze XR–36, Development of.** May 27, 1949.

(3) NOL Sketch 70998, **British 2 Pounder P. D. Fuze, Pressure Type Delay Element.**

(4) JAN–P–223, **Specifications for Black Powder.**

(5) BuOrd Drawing 236222, **0.07 Second Delay Element.**

(6) Picatinny Arsenal Technical Report, Project No. TM1–5016A and TM1–5016B, Report 1, Serial No. 1657, **Investigation of Two Delay Detonators (One Flame Initiated, 0.01 Second, and One Stab Initiated, 0.02 Second) Developed by Company A,** July 8, 1947.

(7) Aberdeen Proving Ground BRL Report No. 690 **Short Delay Baffle Detonators for Anti-Aircraft Contact Fuzes.** February 1949.

(8) NAVORD Report 2261, **Burning Characteristics of Manganese, Barium Chromate and Lead Chromate Mixtures,** by E. E. Elzufon.

(9) NAVORD Report 2158, **Effect of Particle Size on the Burning Rate of Delay Mixtures,** by R. H. Comyn and E. E. Elzufon.

(10) NAVORD Report 1773, **Development of Mixing Procedures for Gasless Fuze Powders,** by R. T. Skelton.

(11) NAVORD Report 2262, **Effect of Loading Variables on the Burning Characteristics of Delay Powders,** by E. E. Elzufon.

(12) NAVORD Report 2215, **Summary of Gasless Delay and Igniter Mixtures and Their Performance**, by R. H. Comyn.

(13) NAVORD Report 1787, **Effect of Pressure on the Burning Rate of Gasless Delays**, by R. H. Comyn and R. T. Skelton.

(14) NAVORD Report 1815, **Instrumentation for the Measurement of Gases Evolved from Burning Delay Powders,** by R. T. Skelton.

Chapter 6

CHARACTERISTICS OF LEADS

Section 1.—General

Definition of a Lead

A lead is that explosive component of the firing train of a fuze which is located between the detonator and the booster. The transmission of detonation from a detonator to a booster may involve propagation across a variety of discontinuities, such as air gaps and/or metal disks or walls, and through constricted channels. The mere fact that a detonation wave has once been set up in an explosive charge is by no means a guarantee that the wave will continue to propagate. The wave may continue with a lower and lower velocity until eventually it is moving so slowly that chemical decomposition ceases (ref. (1)).

There may be one or more leads to complete the path of the firing train between the detonator and the booster. If the lead following

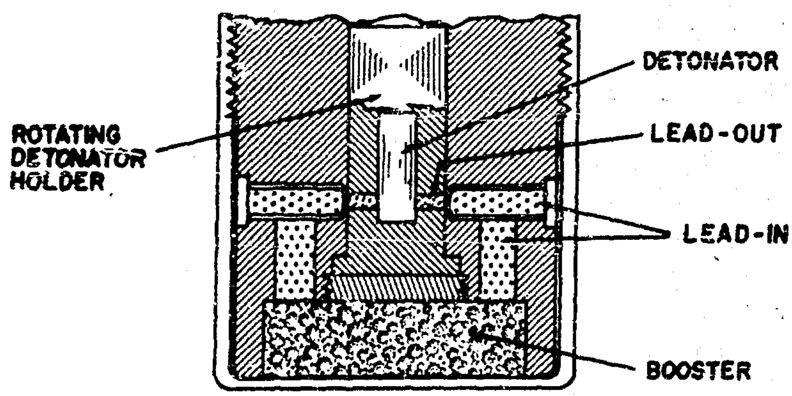


Figure 6–1. Location of Lead-out and Lead-in in the Firing Train. Armed Position.

the detonator is located in the same fuze part as the detonator, it is called a lead-out. If the lead is located in the same part as the booster, it is called a lead-in (fig. 6–1). In some cases the lead is located in a part of its own in which case the suffixes are omitted (fig. 6–2). In figure 6–1, the firing train is shown in the armed position. When in the unarmed position, the detonator holder is rotated 90° from the position shown.

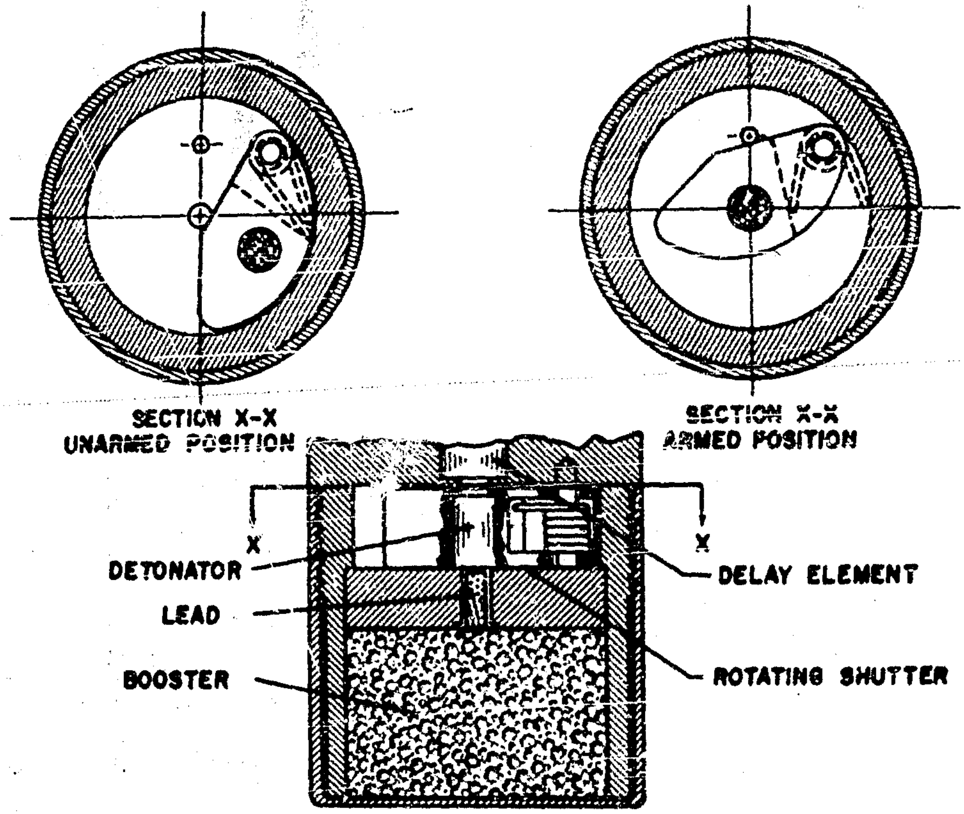


Figure 6–2. Location of a Lead in the Firing Train.

Purpose of a Lead

The purpose of a lead is to transmit the detonation wave from the detonator to the booster.

For a fuze to have maximum safety, the explosive train must be interrupted until the fuze is armed. The interruption is made at the detonator and is usually accomplished by installing the detonator in a rotor, slider, or shutter. Explosive material following the interruption usually consists of tetryl or other material of less sensitivity. Since the lead following the detonator can be of a comparatively small diameter, small and compact mechanisms can be designed to provide the interruption or discontinuity in the explosive train until the instant of arming.

Section 2.—Construction

In the design of explosive leads, the lead holes should be carefully dimensioned with close tolerances. It is imperative that the ram of the loading tool not bind on the wall of the hole or on the wall of the cup.

Some difficulty may be experienced if die-cast metal is used for manufacturing fuze components which contain detonators or leads. The metal may be too brittle, and there is the possibility that an imperfection or hole may be at a critical point. However, these conditions may not persist since die-cast alloys and the methods of casting are rapidly improving.

Material

Tetryl is almost universally used as the explosive charge in leads. Some experimentation has been done with pentolite and other explosive materials; however, at this writing, none of them has been accepted as superior to tetryl for use in fuzes.

Size

Under any given set of loading conditions, there is a minimum diameter of the explosive charge that will support stable detonation. If the diameter of the lead is below this critical value, the detonation will be attenuated until it eventually fails, regardless of how high the velocity of the initiating shock wave may be. The critical diameter for tetryl is about 0.07 inch under the conditions normally used in fuzes.

In general practice, the diameters of leads vary from 0.075 inch to 0.250 inch. The ratio of length to diameter usually ranges from 1/1 to 3/1; however, ratios of 6/1 or higher are sometimes used if necessitated by the design of the mechanism. Experiments have shown that a detonation wave in a straight lead 0.075 inch in diameter and 3.0 in length will continue to propagate at a stable velocity. The length to diameter ratios are not critical and are established only on the basis of structural arrangement of the mechanism. However, the longer the lead, the more difficulty arises in loading it and controlling the density of the explosive. Ratios less than 1/1 are usually avoided since a wafer type charge is structurally weaker and subject to breaking, flaking, or dusting.

If an explosive train contains more than one lead, as shown in figure 6–1, each successive lead should be of a larger diameter so that the intensity or the effective energy of the detonation wave continues to build up as the wave follows the constricted explosive channel to the booster. If the diameter of the leads are gradually increased, the difference between the size of the last lead and the booster is not great and will result in greater assurance of initiating the booster charge. This topic is discussed in more detail in chapter 8. Explosive authorities have stated that the optimum shape for the lead charge would be similar to that of an exponential horn. A truncated cone shape would

approximate the horn shape and would be better than the straight lead. These shapes, however, would present problems in both manufacturing and loading; in most fuze designs, they would increase the size of the fuze and, in turn, the size of the fuze adapter in the missile.

Control of Dusting or Flaking of Leads

The lead is adjacent to the mechanical safety mechanism that furnishes interruption to the explosive train; accordingly, it is important that the explosive material not dust or flake into movable parts. Flaking or dusting would present a hazard, because of the possibility of premature ignition brought about by pinching the loose particles between metal parts of the mechanism under accelerations produced in transportation, especially those encountered in projectile fuzes when fired from a gun. Other less serious troubles would be binding of movable parts and loss of some of the lead charge. Control of the dusting or flaking can be accomplished by three methods.

(*a*) A thin metal diaphragm can be placed between the safety mechanism and the lead.

(*b*) The exposed lead charge can be coated with lacquer or varnish.

(*c*) The lead can be loaded in a thin copper cup.

The disadvantages of the metal diaphragm are the possibility of omission during assembly and the danger that it may split and allow hot gases to reach the lead explosive if the detonator is initiated while in the unarmed position.

The lacquer or varnish seal has the disadvantage of presenting a possibility of gumming of the movable metal parts in contact with it if not carefully applied and dried.

The cup method is superior. It serves exceptionally well as a seal in the event of initiation of the detonator in the unarmed position and eliminates the possibility of dusting or flaking into moving parts.

Allowable Gaps (Air, Metal, Etc.)

The gap across which a detonation wave will propagate is a function of a large number of factors. Some of them are:

- Type of explosive on each side of the gap.
- Densities.
- Diameters.
- Particle sizes.
- Confinement of the charges and length of the explosive column preceding the gap.

Shaped-charge components have been developed that will transmit detonation over an air gap of several inches. A detailed discussion of allowable gaps is given in section 3 of chapter 8 (page 8–11).

Section 3.—Types of Leads

Cup-Type Lead

The cup-type lead is used wherever possible and practicable. The diameters of cup leads vary from a minimum of about 0.093 inch to approximately 0.200 inch.

In designing the lead cup, the thickness of the cup bottom is of the utmost importance. It should be thin so as to offer as little resistance as possible to the detonation wave from the detonator. On the other hand, the metal must be sufficiently thick and ductile to prevent failure by splitting and exposing the lead charge in the event of detonation of the unarmed detonator. Copper or gilding metal permits easy fabrication and provides adequate safety. Practice has shown that a bottom thickness of from 0.005 inch to 0.010 inch, depending on the diameter, is satisfactory for the large majority of cases. Two methods are used in the assembly and loading of cup-type leads. In general, both methods represent satisfactory techniques.

Army lead cup design. The Army preloads the lead cup, which is pre-flanged as shown in figure 6–3. The loaded cup is then inserted in the fuze bulkhead and crimped in place as shown in figure 6–4. The seal between the detonator chamber and the booster cavity thus depends on the crimp.

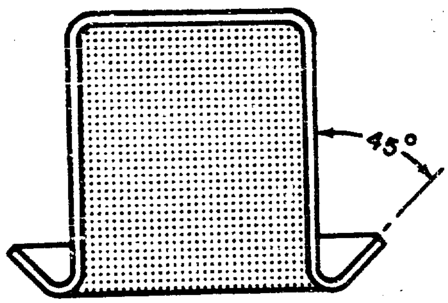


Figure 6–3. A Pre-flanged Lead Cup Used by the Army.

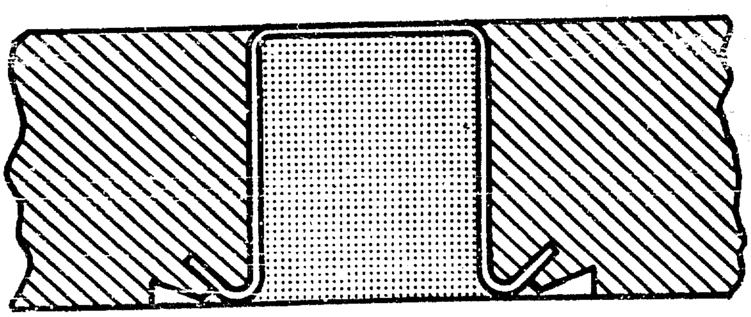


Figure 6–4. Army Lead Cup Inserted in Fuze Bulkhead.

This type of design has some distinct advantages: (*a*) Preloading of the small cup permits use of smaller loading tools and fixtures.

(*b*) Less handling of heavier components.

(*c*) A loose fitting booster pellet does not affect the security of the lead in the bulkhead unless high set-back accelerations are encountered.

There are disadvantages, also, to this type of design:

(*a*) The crimping operation requires additional machining of the bulkhead to accept the flange.

(*b*) Additional handling of the loaded lead when stripping from the loading tool and subsequent insertion and crimping in the bulkhead presents the possibility of disturbance of the charge.

(*c*) In projectile fuzes where high accelerations are encountered in setback and the booster pellet is loose fitting, there is a possibility of the lead charge slipping backward and thus increasing the gap between the detonator and the lead charge.

Navy lead cup design. It has been the practice of the Navy to load the lead in place. The empty cup is placed in the bulkhead and

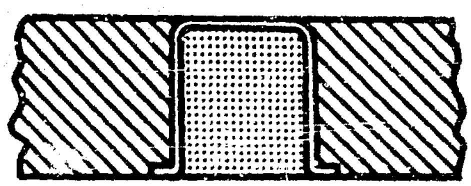


Figure 6–5. Lead Cup Placed in Fuze Bulkhead, Then Flanged.

flanged (fig. 6–5), and the explosive charge is then pressed into place. This operation expands the sides of the cup tightly against the walls of the bulkhead lead hole. No crimping is employed and a close fit is dependent upon the swelling of the ductile cup against the side walls. The flange serves to secure the lead in the fore direction.

This type of design has the following advantages:

(*a*) No handling of lead after loading thereby minimizing the possibility of charge disturbance.

(*b*) Simpler hole in bulkhead.

(*c*) Soft steel or brass flanging tool sufficient.

Disadvantages of this type of design are as follows:

(*a*) Increased handling of heavy fuze bodies.

(*b*) Larger loading tools necessary.

(*c*) Loose fitting booster pellet may leave entire lead assembly unsupported in aft direction.

Non-cup Type Leads

The non-cup type lead (or open-type lead, as it is sometimes called) is often used where the fuze parts and the leads are so small that it would be impractical to use a cup. In this type of lead, which may be as small as 0.075 inch in diameter, the lead charge is loaded directly into the bulkhead or other fuze component without benefit of a cup. The exposed end of the lead charge must be sealed by a lacquer or varnish to prevent or minimize the possibility of dusting or flaking into the moving parts. Great care must be taken to prevent excess coating of the lead or on the metal around the lead charge to prevent interference with proper arming of the safety mechanism. Thorough drying must be accomplished for two reasons:

(*a*) To reduce the possibility of the moving parts becoming gummed and inoperable.

(*b*) To insure against volatiles being entrapped in the interior of a sealed fuze where they may attack other types of explosive charges or the metal surfaces.

In designs where safety devices slide or rotate on the lead charge bulkhead, the non-cup lead should be loaded approximately 0.005 inch below the surface to permit space for the sealing material (fig. 6-6).

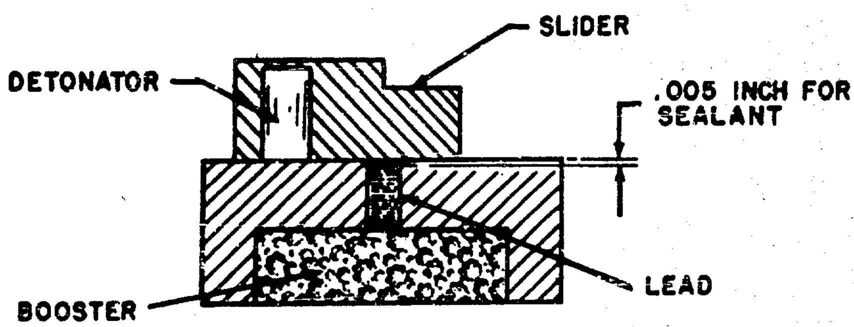


Figure 6–6. Non-cup Type Lead.

Where high shock conditions are likely to be encountered, some provision must be made to further secure the lead charge in place by supplementing the side wall friction obtained during consolidation. Scoring of the wall of the lead hole has been used satisfactorily as shown in figure 6–7. Scoring can be accomplished by tapping the

Figure 6–7. Scoring of the Wall of the Lead Hole.

lead hole and then passing a drill through to remove the crests of the threads (unless very fine threads are used); thus, the severity of the scoring is tempered to reduce the possibility of loss in charge density by binding in the scores or grooves. For this type of lead, loading pressures of 15,000 to 20,000 psi are usually used.

It is often desirable and advantageous to load the lead by one of the following methods:

(*a*) If average accelerations are to be expected, as encountered upon impact of light plate or water, tetryl pellets (preformed at 10,000 psi) may be used for the lead.

(*b*) If high accelerations are expected, as encountered upon impact of heavy armor plate, tetryl pellets that have been preformed at approximately 50 percent of the final loading pressure may be used and then reconsolidated in place at the final pressure.

Section 4.—Loading Techniques

The lead is one of the most critical components of any explosive train. A large percent of ammunition lot failures experienced by loading plants during World War II were traced to improper consolidation of the lead charge. Low order functioning was the usual result.

Loading pressures vary in practice from 5,000 psi to 20,000 psi, depending on the acceleration forces encountered by the missile or weapon in launching or at impact. Leads for general-purpose bomb fuzes are pressed at the lower pressures; whereas, armor piercing bomb and projectile fuzes use the higher pressures. In general, 10,000 psi serves well in the majority of applications; tetryl has a density of about 1.58 at this pressure. Occasionally, loading specifications call for the lead to be loaded to a certain density rather than at a certain pressure.

Tetryl approaches its maximum density (of approximately 1.73) when pressed at 26,000 psi. The sensitivity of tetryl decreases as the loading pressure is increased (sec. 2, page 7-12). Recrystallized tetryl is used for lead loading. The coarser grain sizes are undesirable because it is more difficult to attain a uniform density while pressing. Use of the coarser grains may cause low order detonation. One of the Navy loading plants has made it a practice to use tetryl held on a 60-mesh screen (U. S. Standard) and passed on a 40-mesh screen for making leads. The remainder is used for the manufacture of booster pellets. In order to insure free flowing of the tetryl in pelleting presses and loading tools, it is permissible to add 2 percent graphite, which acts as a lubricant.

Leads with a length to diameter ratio of 1.5 to 1 can be loaded in a single increment; however, those with greater ratios should be loaded in multi-increments to reduce the density gradient.

During loading the closed end of the lead cup must be firmly supported so that after loading the end of the lead cup will be flush with the bulkhead and will not cause interference with the movable parts of the mechanism.

In the loading of leads, it is desirable that the loaded lead be flush with the surface of the metal after the compression operation except under conditions previously noted in the preceding section and in cases where it is difficult to check the height of the loaded lead. In the latter case, it is sometimes desirable to "overload" the lead slightly (not to exceed 0.04 inch or 0.05 inch) and then break off the excess. The "break off" is accomplished by rotating the funnel of the loading tool. In all instances the "break off" will be practically flush with the surface of the metal, provided the radius of the arris at the mouth of the lead hole does not exceed 0.004 inch or 0.005 inch.

Close inspection of the loading of leads is a necessity. Binding of the loading ram in the loading tool or excessive friction in the loading press are two things which must be avoided. If either of these conditions is present, the loading pressure cannot be controlled and improper consolidation will result. The design of the loading tool is a very important factor and is discussed in detail in chapter 10.

During World War II, many loading plants maintained a close check on the density by carefully pressing out the loaded pellet and dropping it into aqueous solutions of zinc chloride ($ZnCl_2$) prepared to different densities. The density of the pellet was bracketed between the densities of the two solutions wherein the pellet sunk and floated.

Section 5.—An Actual Firing Train Design

An actual design of a firing train for a fuze (drawn to scale) is shown in figure 6–8. This illustration will enable the reader to obtain a comparative view of the related components. This particular design was selected as an example because it utilizes three different types of leads. Lead A is a non-cup type lead with a scored wall; lead B is a cup lead; and lead C is a non-cup lead made of preformed pellets. The dimensions of the lead charges are given in table 6–1. The dimensions and tolerances of the lead holes, lead cup, and related parts are given in figure 6–9.

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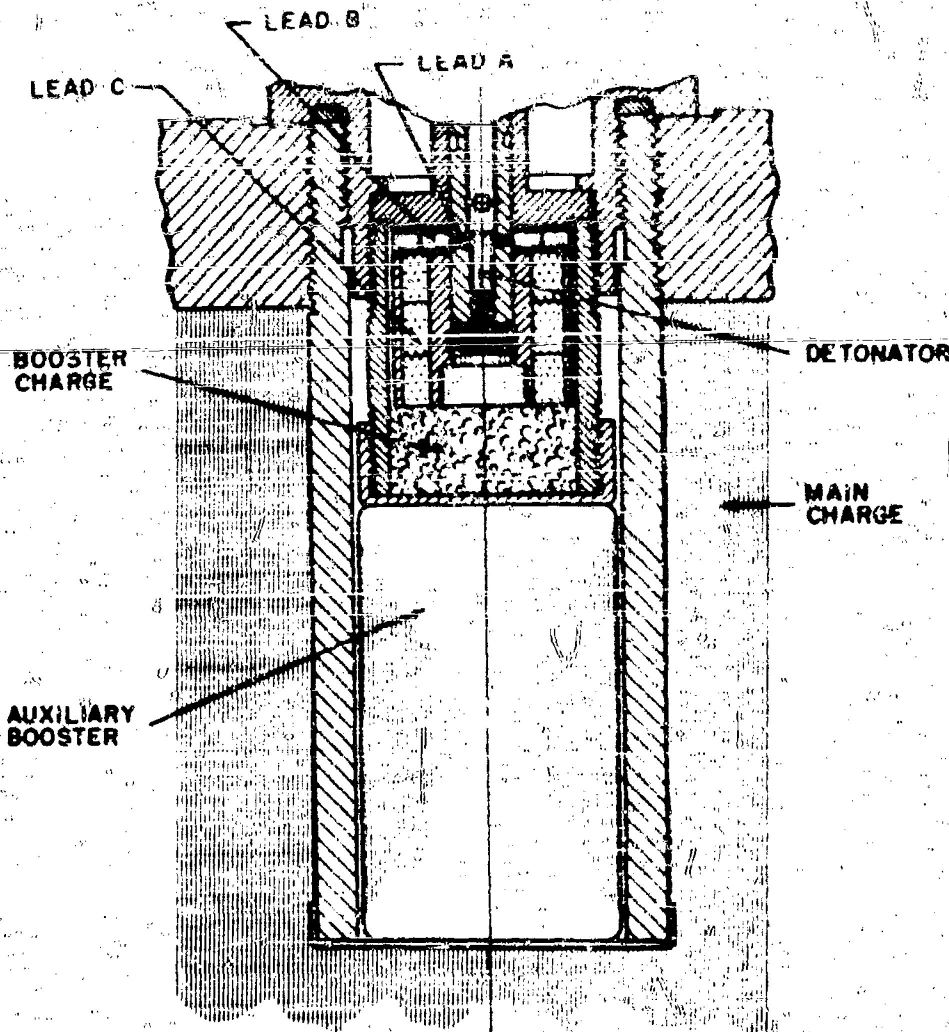


Figure 6–8. An Actual Design of a Firing Train of a Fuze. Drawn to Scale.

TABLE 6-1.—*Dimensions of the Lead Charges in an Actual Firing Train Design*

Lead	Diameter (inches)	Length (inches)	Number of increments
A	0.068	0.137	2
B	[illegible]	.411	2
C	[illegible]	1.071	(1)

(1) 3 pellets.

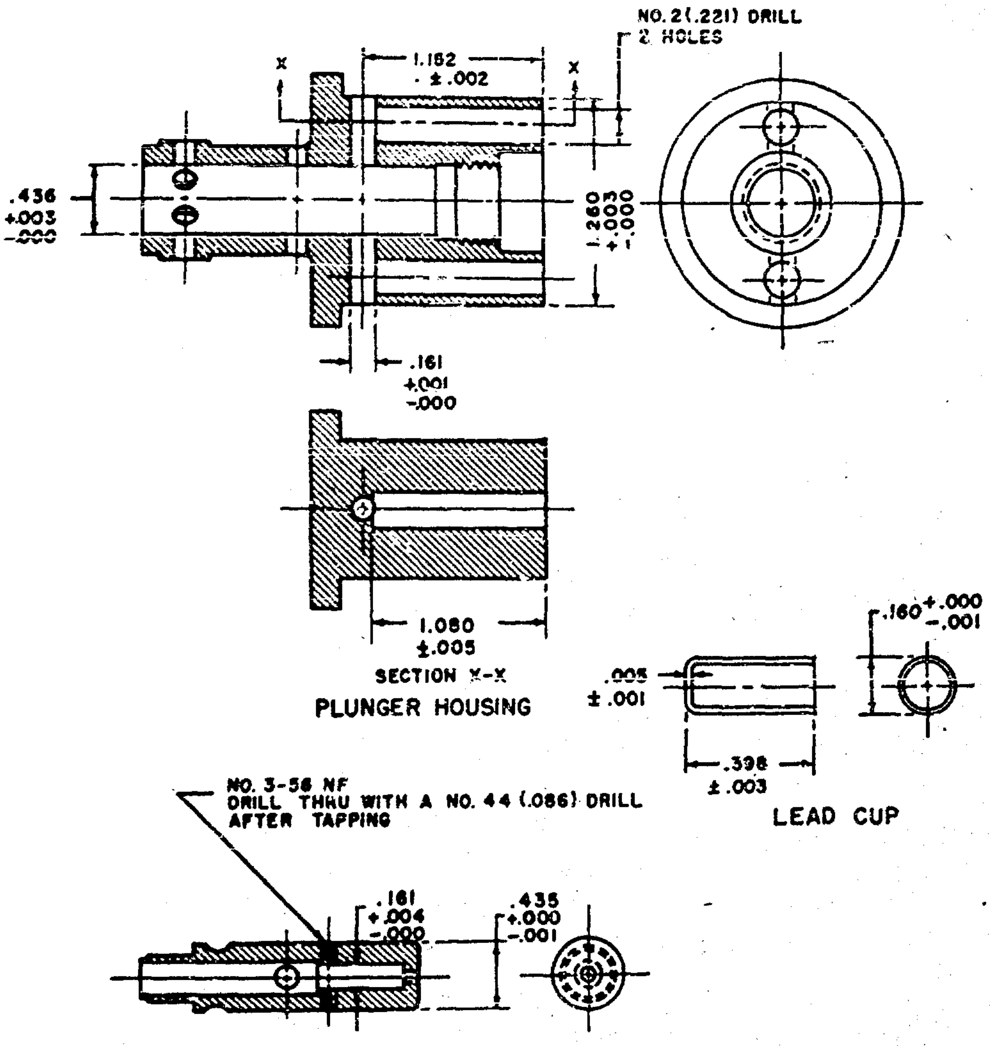


Figure 6–9. Dimensions and Tolerances of the Lead Holes, Lead Cup, and Related Parts of the Firing Train of the Fuze Shown in Figure 6–8.

Section 6.—References

Parenthetical number preceded by the letter "S" is Naval Ordnance Laboratory file number.

(1) NavOrd Report 70–46, Chapter 3, **The Stability of Detonation,** Frick Chemical Laboratory (S–10775).

Chapter 7

CHARACTERISTICS OF BOOSTERS

The booster is the final element in the explosive train. It is a charge of moderately sensitive high explosive that is initiated by a detonator or a lead and that in turn initiates the main charge in the ordnance item.

For convenience, the discussion of boosters is divided into construction, sensitivity, and output.

Section 1.—Booster Construction

General Considerations

This section concerns itself with a treatment of booster construction as represented by current domestic fuze practice. Those performance requirements of a fuze which affect the selection of the size, type, shape, and construction method for any given booster design are considered. The type of ordnance item of which the fuze is a part determines the use and forces to which the booster will be subjected and hence sets limitations on the location, method of loading, and, sometimes, the size of the booster to be used. For example, different designs must be used when boosters are loaded in a fuze for use with armor-piercing projectiles as compared with those in fuzes to be used in missiles not subject to heavy impacts. It should be noted that many designs represent a compromise with respect to ideal booster requirements, that is, fuze geometry, weight, manufacturing processes, etc., may necessitate a modification of a desired design.

Current Practice

Materials. There are a number of potentially useful high explosives suitable for loading boosters, but tetryl is used almost exclusively in this country for booster applications. Pentolite and various RDX/wax mixtures (ref. (12)) are used, or have been proposed for use with some service designs. Pressed TNT is not used as a primary booster because it is not reliably initiated by tetryl leads of the size employed in current fuze designs; however, it is often employed as a secondary or auxiliary booster between the fuze and the main charge. Consideration of examples of current designs will be restricted to those booster assemblies employing tetryl, but the characteristics cited are also applicable to the other materials mentioned.

Tetryl used for booster applications may range in granulation from eight to one-hundred mesh and may include tetryl recovered from

other loading operations. Approximately two percent of natural graphite, barium, or calcium stearate is usually mixed with the granulated tetryl before pressing, to serve as a lubricant for both the charge and the loading tool during the consolidation of the load.

Loading. A primary consideration in the loading of boosters is the problem of maintaining proper densities throughout the charge, since considerable variation in the booster sensitivity and output occurs with changes in the charge density. In current loading practice, tetryl is pressed to a density of 1.40 to 1.55 (with recent trends indicating the future use of densities as high as 1.65). The density is indicated on the drawing of the fuze or other device by specifying a given weight of charge together with the consolidating pressure and/or the cavity or pellet form into which it is to be pressed. Specifications may set forth a required density in lieu of one of the above conditions.

Maintenance of the required densities is generally the limiting factor with respect to determining the size of charge that may be pressed in a single loading operation. For example, the AN–M103A1 Bomb Fuze requires a cylindrical tetryl booster 1.295 inches in diameter and 1.60 inches long. It is common practice to produce this booster by pressing the charge in several increments or by stacking preformed pellets, because it would be difficult to maintain the density within specifications if the charge were pressed in a single increment. Consolidating pressures for the loading of tetryl boosters generally range from 5,000 psi to 15,000 psi depending, of course, on the size and shape of the charge being pressed.

Assembly methods. In general there are three methods of loading the booster charge in the fuze:

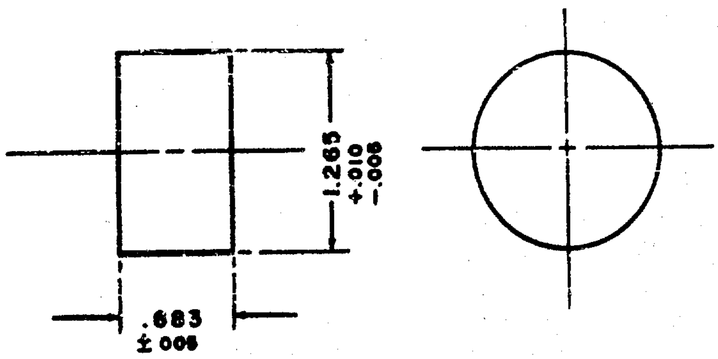
(*a*) By placing fully consolidated preformed pellet or pellets in a suitable cavity or housing of the fuze.

(*b*) By pressing a loose tetryl charge into a suitable cavity of the fuze assembly under final consolidating pressures.

(*c*) By placing a lightly consolidated preformed pellet in a cavity of the fuze assembly and applying full consolidating pressure with the pellet in place.

Method (*a*) is a technique much employed in fuze practice. Pellets can be produced to close tolerances and with great uniformity when pressed by automatic equipment. It is to be noted that when pellets are pressed with a static anvil in the mold a density gradient exists through the length of the pellet, with the greatest density and hence the least sensitivity in that end adjacent to the ram in the loading tool. Accordingly, an identifying mark is generally formed into the denser end of the pellet in order to identify the less dense face so that it may

be placed adjacent to the source of initiation. Necessity for orientation of the pellet faces is undesirable since additional care is required during assembly, and another opportunity for error is afforded. The use of pellet molds with double rams considerably reduces the importance of the variation in density within the pellet and hence eliminates the orientation requirement. Figure 7–1 represents an example of a booster of this type, with the conventional loading instructions indicated. It is usually necessary, when using pelleted boosters in a fuze assembly, to compensate for tolerance accumulations which, if



LOADING INSTRUCTIONS

PELLET TO BE SEPARATELY MOLDED BY MACHINE AND TO CONSIST OF APPROX 22 GRAMS OF TETRYL PRESSED AT 10,000 PSI IN ONE PRESSING
DEAD LOAD ON RAM 12,270 LBS SPECIFIC GRAVITY OF PELLET 1.48 TO 1.55, ALL PLACES END OF PELLET TOWARD LOADING RAM TO BE MARKED BY A SINGLE GROOVE TO BE ASSEMBLED WITH MARK TOWARD BOOSTER CAP
ADDITION OF NOT MORE THAN 2 % POWDERED NATURAL GRAPHITE TO TETRYL IS AUTHORIZED

Figure 7–1. Booster Pellet, Tetryl.

uncorrected, would allow movement and consequent potential break up of the booster pellet before functioning. Felt or paper spacers are employed for this purpose; but, in all cases, the pellet must be as rigidly mounted as possible, depending, of course, on the forces to which the fuze will be subjected.

Method (*b*) as noted above is principally employed in applications where greater strength in assembly is required, and is commonly used in fuzes for rounds likely to undergo severe impacts, with their resultant high retardation forces. This type of loading is also used where unusual cavity shapes require it. The principal drawback of integral loading is that it requires handling the relatively large and

heavy fuze bodies during the loading operation. It is to be noted that it is difficult to specify a fixed weight of charge for loading, because of tolerances allowed for machining cavities. For this reason, it is customary to load cavities, with the consolidating pressure specified, until the face of the charge is flush, within tolerances, with a surface or other reference. Although it is not considered to be good loading practice, cavities can be, and sometimes are, overloaded and the excess tetryl broken off or removed in a trimming operation. Additional resistance to break up upon impact can be attained by having very

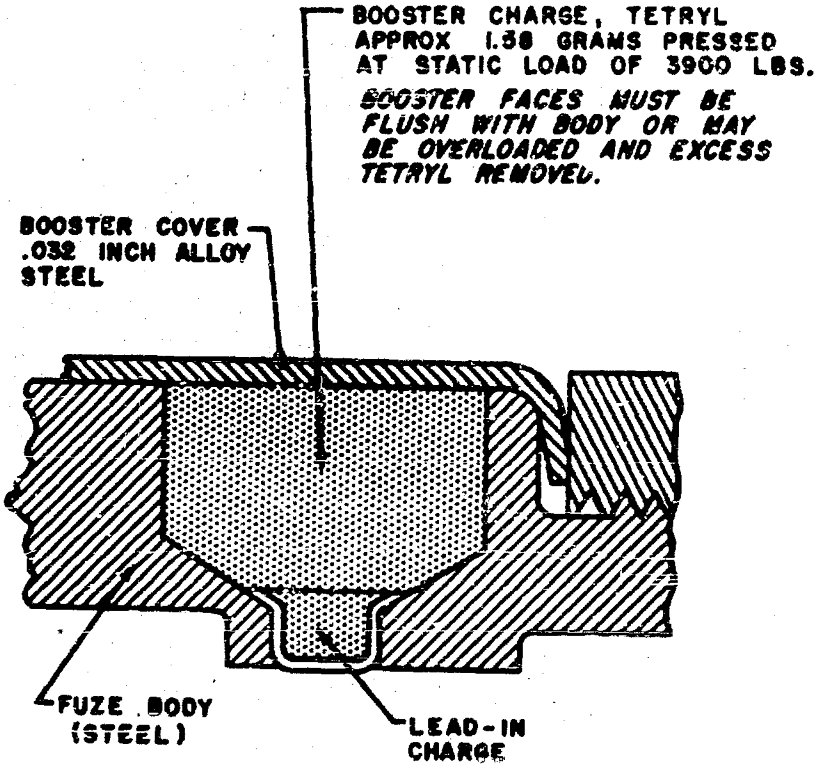


Figure 7–2. Booster Assembly for Base Detonating Fuze Mk 21 Type.

rough or scored cavity walls to retain the charge in position. Figure 7–2 represents an example of a booster integrally loaded in accordance with current loading instructions.

Consolidating a preformed pellet in place in a fuze assembly (method (c)), will produce a stronger mounting for the booster than if pelleted boosters are used; however, this method produces a weaker mounting than that resulting from the booster being fully consolidated in place. Method (c) offers the advantage of using a known charge with one consolidating pressure stroke, eliminating several handling operations of the heavy fuze body during loading. This method is commonly employed in the loading of Base Detonating Fuze Mk 28, used in

projectiles not subject to heavy target impacts. It may not be employed in geometrically similar Base Detonating Fuze Mk 21, used in armor-piercing projectiles. This method is suitable for the loading of booster cavities of unusual shapes where movement of the ram into the cavity during the consolidating stroke is restricted, as with bulk loading into elliptical or hemispherical cavities.

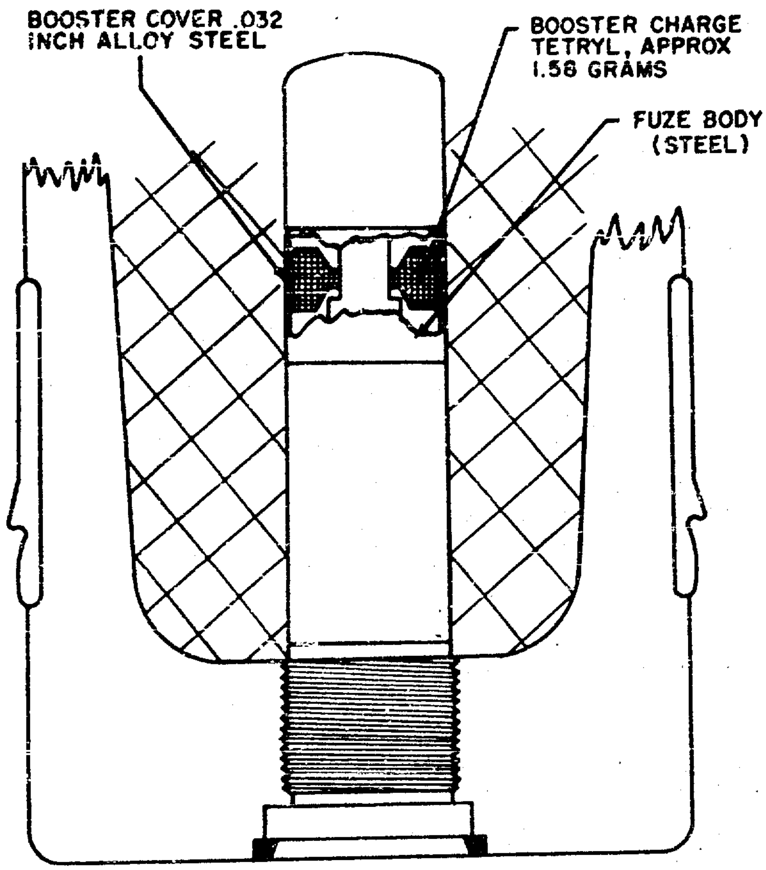


Figure 7–3. Base Detonating Fuze Mk 28 Type, Assembled to 5 Inch A. A. C. Projectile.

Booster shape. The shape of the booster pellet is determined largely by the design, but often it is modified by virtue of mounting requirements or space limitations. For ease in assembly and loading, most current designs utilize cylindrical boosters. However, cylindrical boosters with low length to diameter (L/D) ratios, that is, less than 0.3/1, in addition to being undesirable from the stand point of functioning, are subject to fracture and flaking during handling before and after loading into the fuze. The L/D ratios used in existing designs employing cylindrical boosters range from approximately 0.5/1 to 1.3/1.

Many fuze designs employ non-cylindrical boosters, the need for which is brought about by individual weight, space, or other requirements that necessitate a more complex shape. These may appear in the form of elliptical or compound conical-cylindrical boosters. A booster having an increasing cross section in a direction outward from

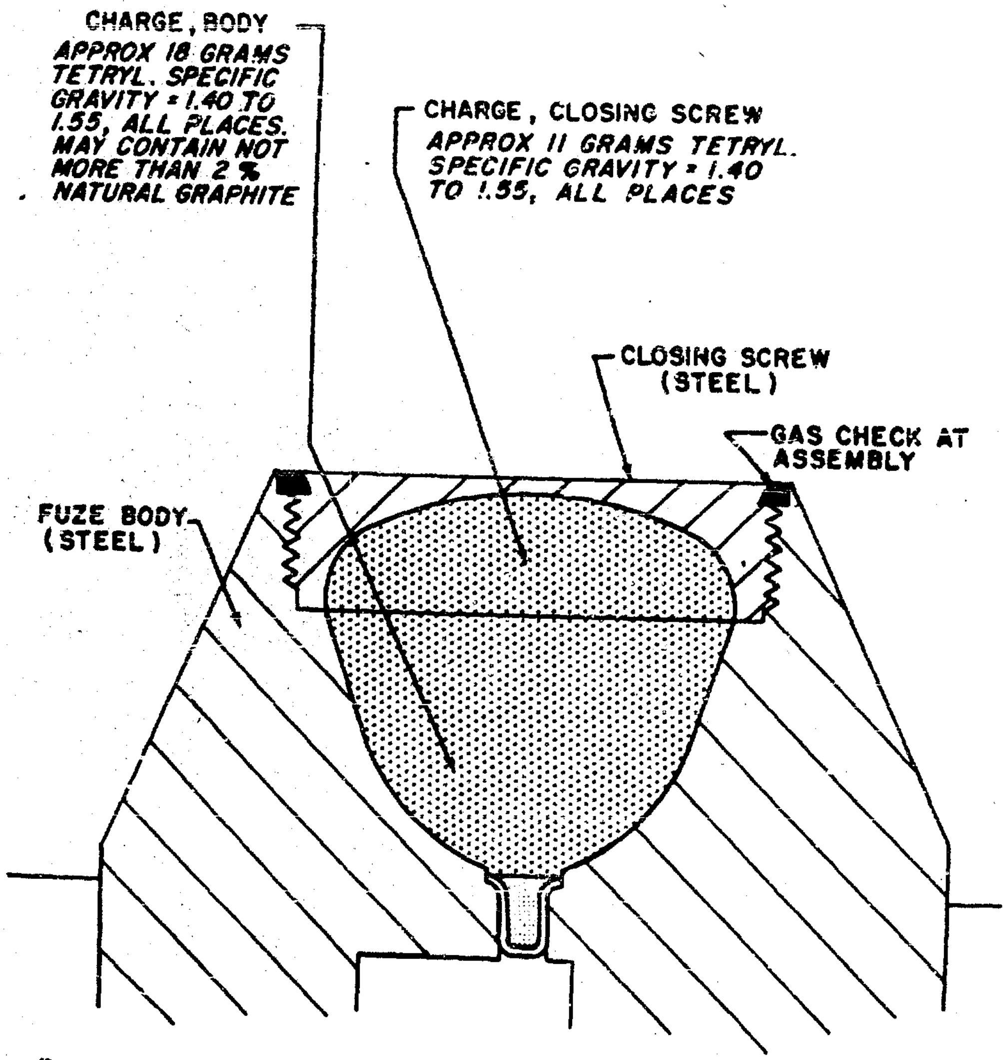


Figure 7–4. Booster Assembly for Base Detonating Fuze M60 Type.

the initiating lead is functionally more efficient in that it results in a maximum development of the wave front in the booster material and results in greater surety of initiating the main charge.

This type of booster will produce a directional wave along the axis of the charge, especially when relatively strong side confinement is used. This characteristic of directional output is utilized in fuze applications, especially for armor-piercing missiles, which often

cannot accommodate large cylindrical boosters because of the difficulty of mounting such charges.

On these missiles, the available charge volume must be utilized as efficiently as possible. This principle will also apply wherever space is a critical factor. Boosters integrally assembled into non-cylindrical cavities are very difficult to load and require greater care in assembly. In addition, they require extra handling and trimming operations and, accordingly they are undesirable from the standpoint of loading in production. Booster designs have been proposed in which the explosive acts as a shaped charge to initiate an auxiliary

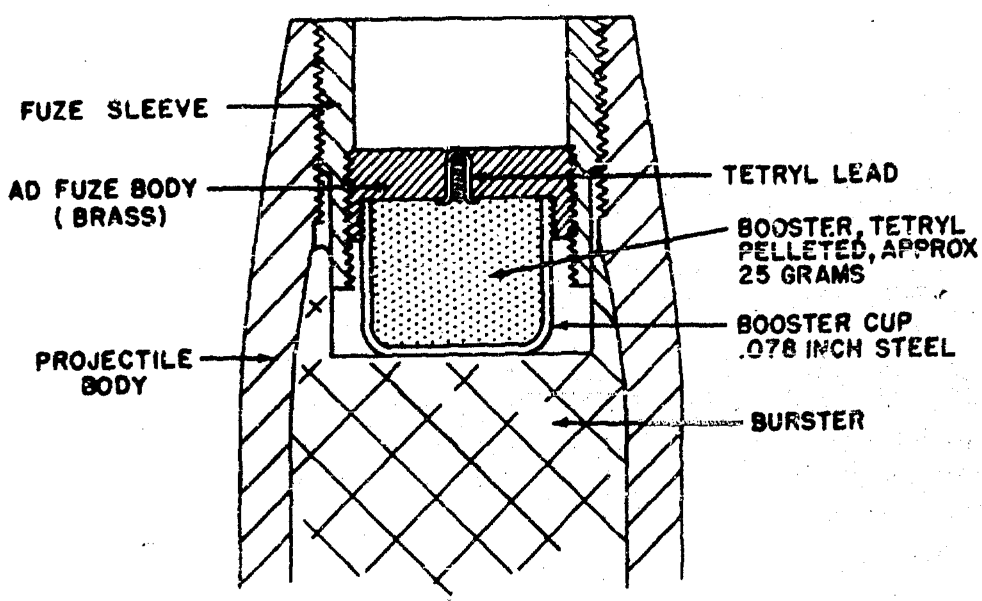


Figure 7–5. Booster Assembly for Auxiliary Detonating Fuze Mk 44.

booster at distances up to five inches. Few such designs have been produced.

Confinement and mounting. In all cases, the booster must be mounted so that it will be functional and remain in position relative to the other mechanical and explosive components of the train while being subjected to all the forces the assembly is required to withstand. Examples of typical variations in booster mounting and the relationship of the booster charge to the burster charge are shown in figures 7–2 to 7–6 inclusive.

Figure 7–2 represents a projectile base fuze of the Navy Mk 21 type. The boosters (two) are pressed into cavities in the fuze body and are confined by solid metal on all sides. The faces of the boosters are covered with 0.032 inch alloy steel sheet. The charge in this case is small, approximately 1.6 grams of tetryl per cavity. The conditions

present in this design may render it critical with respect to reliable functioning of the burster if additional interference is introduced between the booster and the burster charge. This fuze represents an example of an assembly that cannot be modified to receive a larger booster without excessively weakening the structure or increasing the diameter of the fuze body. An auxiliary booster is not used with this type of assembly. Boosters loaded in this manner are very rugged

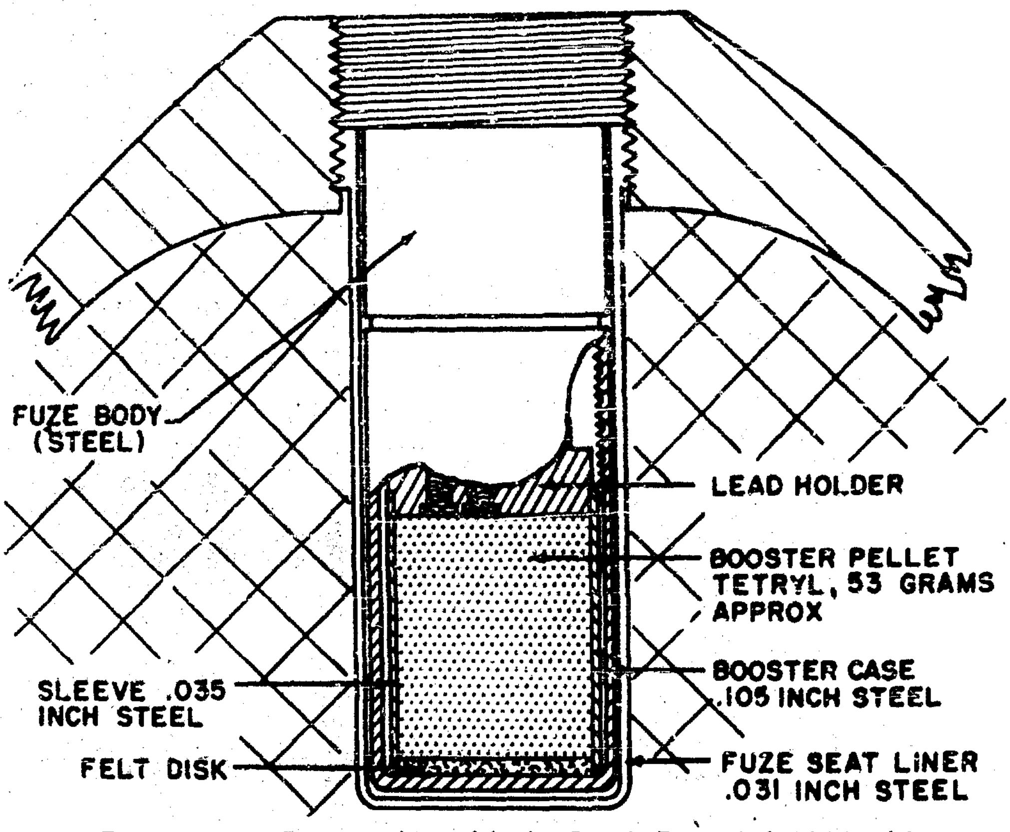


Figure 7-6. Booster Assembly for Bomb Fuze AN-M103A1.

and have withstood severe impacts without fracturing when fired in 6″ to 16″ AP projectiles.

Figure 7-4 represents a projectile base fuze of the Army M60 type and is an example of an undesirable design from the standpoint of ease of loading. This fuze is subject to heavy impacts as a component of armor piercing projectiles. The booster is strongly confined and hence is strongly supported. The charge is pressed in two parts, one part into the body cavity, the other into the closing screw. The tetryl must be loaded flush with the referenced surface so as to insure a continuous charge upon assembly. The booster consists of approximately 29 grams of tetryl, integrally loaded, and pressed to a required density. This fuze is used in 6″ and 8″ AP projectiles.

Figure 7-5 illustrates the booster of the Navy Auxiliary Detonating Fuze Mk 44, which is representative of a type of booster mounting employed for assemblies not subject to large impact forces. The pelleted charge of approximately 25 grams of tetryl is assembled in a 0.078 inch steel cup and threaded into the brass fuze body. This assembly is intended for use with impact fuzes with superquick functioning and with time fuzes for flight functioning; hence, it is normally subjected to no greater forces than those which it undergoes during gun firing. This fuze has been satisfactory for use in projectiles ranging in size from 3″ to 6″, the greater forces being experienced in the smaller calibers. It is common for this fuze to be separated from the burster charge by a 0.025 inch or 0.031 inch fuze seat liner. The degree of confinement of the booster is not great and is determined largely by the initiating fuze body into which this auxiliary fuze is assembled.

Figure 7-6 represents the booster and fuze seat liner assembly of a conventional bomb fuze for general purpose bombs. The pelleted tetryl charge of approximately 53 grams is mounted within a 0.035 inch steel sleeve that is encased by a 0.105 inch steel cup. The pellet or pellets are supported at the proper height by pressed felt disks such that, in the assembled position, the charge isolated from the booster case. This type of fuze is normally fitted into a fuze seat liner of 0.025 inch or 0.031 inch steel incorporated into the munition. The total interference is thus on the order of 0.160 inch of steel between the booster and the main charge. This mounting is not considered sufficiently strong to withstand severe target impacts and remain functional. The surety of functioning is enhanced by the fact that this booster is imbedded within the burster which it is to initiate.

Section 2.—Booster Sensitivity

Various considerations in fuze design place a severe limit on the permissible physical size of the several fuze elements. As a result, the shock produced by the fuze detonator or lead will generally be insufficient reliably to initiate directly the main explosive charge, which, for very cogent reasons, will itself have been designed to withstand very considerable shocks of all sorts. A "booster" is therefore introduced between the fuze lead and the main charge to transmit and at the same time intensify the shock produced by the fuze.

In serving its purpose as a detonation-transfer medium from the small detonator (or lead) to the main charge, a booster must be so designed that it will, itself, be reliably detonated by that train element

preceding it. At the same time, it must be capable of withstanding such extraneous impulses as those resulting from launching accelerations, target or water impact decelerations, and the general shocks of rough handling in loading and transit. These conflicting sensitivity requirements constitute the first phase of the booster-designer's problem, which differs from the second phase (considered in section 3) only in that, whereas both the booster and its preceding train element are generally under the control of the fuze designer, the main charge is generally not under his control, having been designed for maximum damaging power and minimum sensitivity.

Effect of Booster Explosive on Sensitivity

The principal method of achieving the proper sensitivity in a booster has been that of choosing for its fabrication an explosive of suitable sensitivity. The general acceptance, in this country, of pressed Tetryl as a booster explosive is about the only available general sensitivity specification. For weapons in which large boosters may be used, materials even more insensitive per se, such as granular TNT, have been employed; though this particular material seems relatively undesirable both because of its low output and unstable

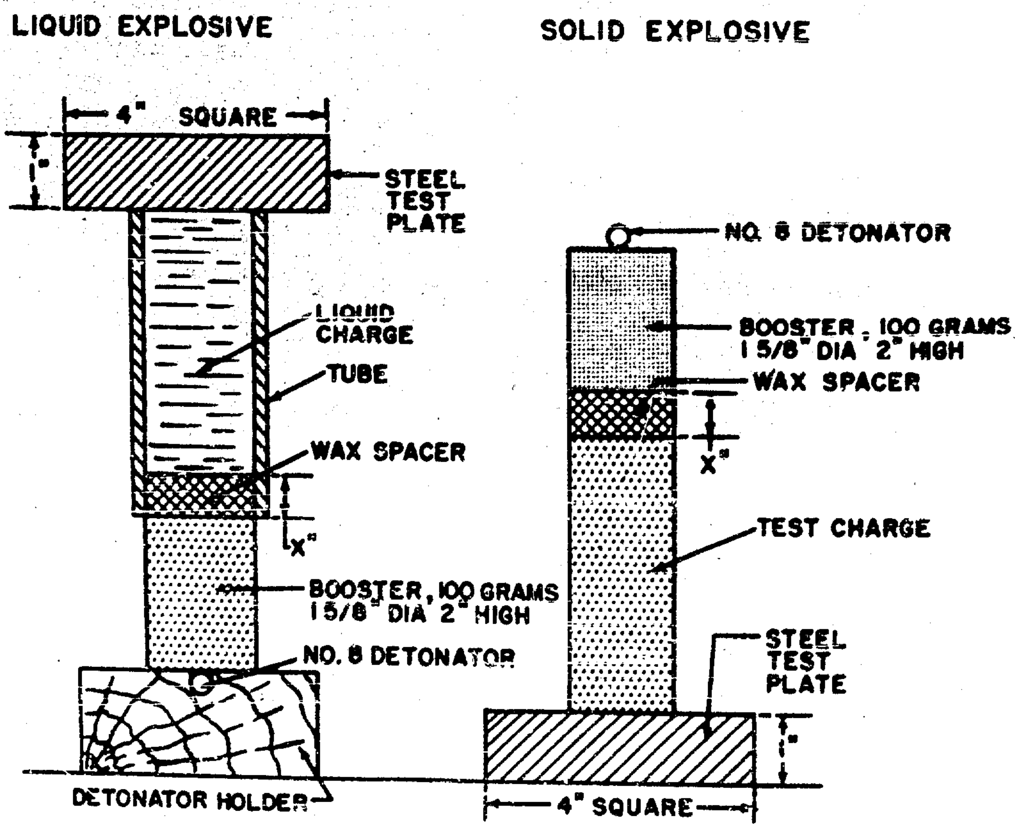


Figure 7-7. Gap Test Arrangement.

density (which might lead, by compaction on impact, for example, to the development of large air-gaps). Table 7–1 presents sensitivity-test results of several kinds for a variety of possible booster explosives, many of which have sensitivities of the same order of magnitude as Tetryl; materials of sensitivities distinctly higher and lower than Tetryl have, however, been included for consideration in special circumstances under which such properties might be required. A schematic diagram of the apparatus used is presented in figure 7–7.

TABLE 7–1.—*Sensitivity Test Values for Possible Booster Explosives*

Explosive	Impact test (H_{50} in cm) [1]	Minimum priming charge test (grams diazodinitrophenol)		Gap test [3] (inches wax)	
		Pressed [2]	Cast	Pressed [4]	Cast
PETN	12	0.09			
RDX	17	.13			
DINA	23	.15	0.29		
Pentolite 50/50	38	.13	.21	2.36	2.68
PTX-2	38			2.32	1.67
RDX Wax 96/4	40.8 (ref. 12)				
Tetryl	42	.17		2.01	
Haleite	38	.19			
PTX-1	46			1.94	1.82
Tetrytol 75/25	70	.19	.31		1.52
Comp. B	82	.21	.33		1.40
Comp. A	80	.21		1.70	
TNT	170	.29	(0.72)	1.68	to 0.82

[1] Drop height in centimeters with a 2 kilogram weight to give 50 percent initiation of the explosive.
[2] Tested at density of 1.4.
[3] See figure 7–7 for diagram of apparatus.
[4] At usual press-loading densities.

Effect of Physical Form of Booster Explosive on Sensitivity

The impact sensitivity tests of table 7–1 have been on granular particles which probably lose their form before they explode, but the minimum priming charge and gap tests have been made on both the cast and pressed form of a number of materials. Both tests agree that any given explosive is considerably easier to initiate when pressed than when cast. Tetryl cannot be cast, but the data in table 7–1 suggest that either cast Pentolite 50/50 or cast PTX–2 might be substituted for pressed Tetryl without substantially changing the sensitivity of the resulting booster, whereas either of these materials, when pressed, would give a distinctly more sensitive booster than Tetryl.

Effect of Booster Density on Sensitivity

The minimum priming charge results given in table 7–1 were determined at density 1.4; the gap test (fig. 7–7) results are for representative loading densities of the materials in question. Consideration of minimum priming charges as a function of receiver-density sug-

gests a general increase in sensitivity with decreasing density; but the results are not uniform (ref. (1)). The precision of the gap test permits a more detailed insight into the effects of loading density upon the ease of initiation. Figure 7–8 shows the critical gap lengths (inches) for several explosives as a function of percent voids. (Good press-loading practice can usually produce pellets having percent voids between 5 and 10 without undue difficulty.) Figure 7–8 reveals that at around 25 percent voids, granular TNT has become almost as easy to initiate as densely-pressed Tetryl; that low-density Tetryl is easier

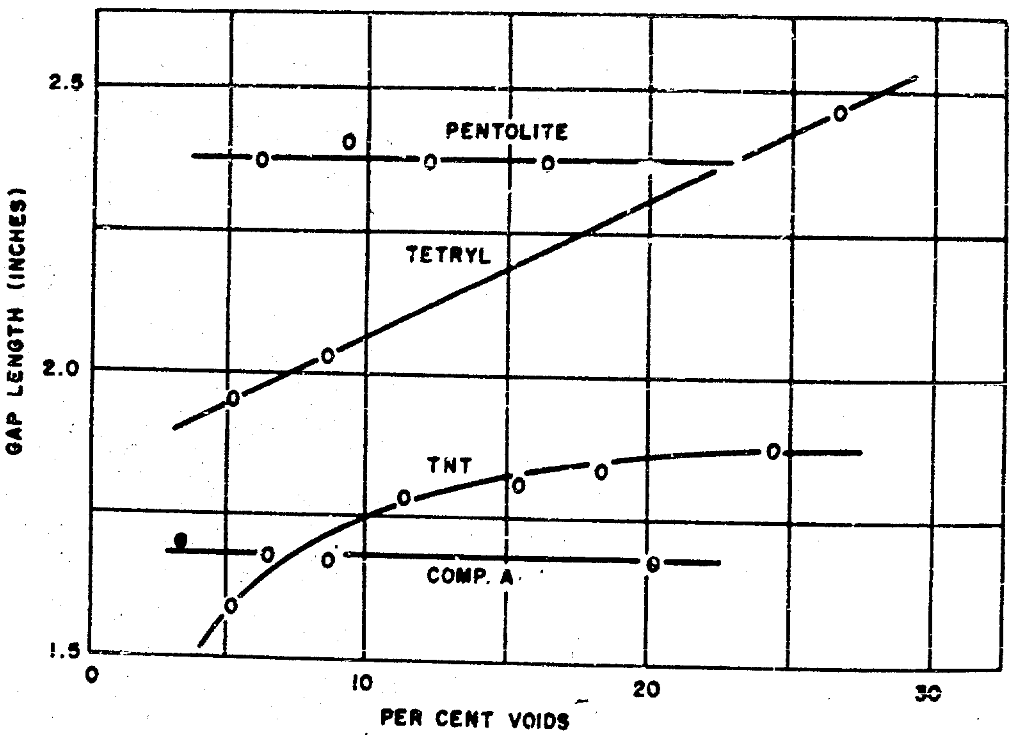


Figure 7–8. Critical Gap Lengths (Inches) for Several Explosives as a Function of Percent Voids.

to initiate than pressed Pentolite; but that with both materials at high density, the Pentolite is much more sensitive.

Such materials as Pentolite and Composition A appear to offer peculiar advantages as booster explosives, because their sensitivities seem to be independent of density over a wide range. It is likely that other materials can be developed which will display this density-independent ease of initiation at any desired sensitivity; Pentolites of other compositions than 50/50, waxed RDX with less than 9 percent. waxed PETN, and waxed Haleite are obvious possibilities. Advantages of such materials are rather clear, but a few might be

pointed out to offset a logical objection to complicating a booster-designer's repertoire with more than one or two explosives:

(*a*) Such materials would not be easier to detonate in bulk, as shipped and handled, than in their high-density, loaded form.

(*b*) With a variety of stable sensitivities to draw upon, the designer could suit the sensitivity to the output of the preceding train element more precisely; production variations in booster density would not affect functioning critically.

(*c*) Materials of this sort may generally be expected to have the highest output performance.

Effect of Booster Explosive Granulation on Sensitivity

It is probable that, even for explosives as sensitive as those employed in boosters, the particle size distribution of the explosive is important for sensitivity, although the details of the effect are not well understood. The data given in table 7–1 and figure 7–8 refer to materials of current production granulation. Generally speaking, finer materials have shorter reaction zone lengths, which aid rapid establishment of stable rates; but also, the more nearly uniform the particle size, the greater the sensitivity. At present, little more than a warning of the existence of the effect can be given.

Effect of Booster Shape and Confinement

Booster shapes, generally speaking, are probably of no importance in booster sensitivity and will be fixed by output considerations. Confinement probably has no effect on booster sensitivity, except to the extent that it may affect the output of the previous element in the explosive train. The absolute booster dimensions, however, are of some importance. A very critical period in the life of the detonation starts where it leaves the small-diameter, confined lead and expands into the larger booster, even though both elements are in perfect contact and of identical composition. While the radius of curvature of the detonation is small, it will proceed at reduced rate; as the radius increases, the detonation will gradually accelerate; moreover, the velocity will be even slower as the angle from the original lead axis increases. In these low-velocity areas, marginal detonations are most likely to fail. Therefore, when leads and boosters must be small, boosters should not have small L/D ratios—probably not much less than unity. For very critical trains in which size must be kept very small in relation to natural dimensions of the detonation, such considerations (ref. (2)) might suggest a lead-booster design in

which the wave divergence is controlled by the use of non-cylindrical lead and booster shapes—together the two might look like a truncated cone or a trumpet.

Variation of Sensitivity with Temperature

At elevated temperatures (in the absences of phase changes or specific physical or chemical alterations of booster materials) sensitivity should, if anything, increase slightly. However, gap tests on Tetryl and TNT at —70° C have shown no measurable decrease in sensitivity at this temperature.

Control of Booster Sensitivity

In the foregoing discussion, reference has been made to the various factors affecting booster sensitivity without explicitly evaluating these factors from the standpoint of their usefulness in the control of booster sensitivity. Generally speaking the designer has three useful controls over the sensitivity of a booster, namely:

(*a*) In the selection of the booster material.

(*b*) In variations of the composition of those materials which are mixtures, such as Comp. A and Pentolite.

(*c*) In the selection between cast and pressed forms, where both are available for the same material.

Methods (*a*) and (*c*) have been discussed in connection with table 7–1 and are the controls which have principally been used in the past. The full possibilities of method (*b*), however, have probably not been realized. Merely by varying the wax content of Comp. A, for example, a series of high output boosters of widely varying sensitivity becomes immediately available. This method deserves further consideration on the part of fuze designers.

Section 3.—Booster Output

In this section, consideration is given to the transition from booster to main charge. In treating this problem it is necessary to consider both those factors affecting the output of the booster and those factors on which the complete and successful detonation of the main charge depends. Although normally the size, shape, and composition of the main charge are outside the control of the fuze designer, all three must be considered by him in the process of designing an adequate booster for a particular weapon.

In order that the fuze designer may have an adequate understanding of the process which occurs in the transition booster to main charge, a qualitative discussion of the principles underlying the initiation and

propagation of detónation in an explosive are given. Following this discussion, those factors affecting the intrinsic output of the booster itself are discussed, and finally, those factors affecting the transmission of the output of the booster to the main charge are treated.

General Considerations (Refs. (6) and (7))

A detonation wave is an intense shock or compression wave of forward moving material that is supported by the very rapid exothermic decomposition of the explosive immediately behind the shock front. The pressure profile of a detonation wave occurring in a charge of finite extent has the appearance shown in figure 7–9.

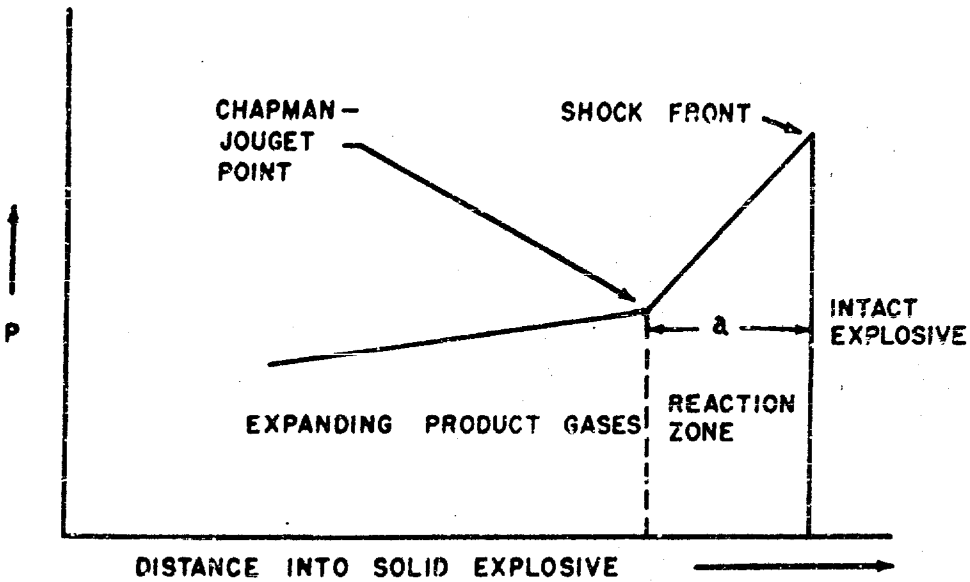


Figure 7–9. Pressure Profile of a Detonation Wave Occurring in a Charge of Finite Extent.

At the shock front, the pressure rises abruptly to a very high value, of the order of 400,000 atmospheres. The resulting rapid compression of the solid explosive raises its temperature to perhaps 2000° C, and the explosive decomposes rapidly, with the evolution of energy. This decomposition requires something less than one microsecond for completion, and, in this time the shock front will have proceeded on a further distance. "a" is called the reaction zone length, and the point at which reaction is complete is called the Chapman-Jouget point or Chapman-Jouget plane. Immediately behind the Chapman-Jouget plane the product gases, which have been compressed to a density even higher than that of the original explosive, are moving forward (that is, in the same direction as the detonation wave) with a velocity

of some 1,800 meters per second, about one-fourth as great as the velocity of the detonation wave. At a still greater distance from the shock front, the product gases expand into the surrounding medium. At the Chapman-Jouget point, the pressure and temperature are of the order of 200,000 atmospheres and 4000° C. For a plane detonation wave of infinite extent, P, T, "a," and D (the detonation velocity) have definite values for a given explosive, and depend principally on the physical and chemical properties of the unreacted explosive and its detonation products, and on the density of loading.

Consider now what occurs when a cylindrical booster of very large diameter is used to initiate a cylindrical main charge of equal diameter. For the moment, it will be assumed that the detonation wave in the booster is plane and is moving with its stable velocity, D. Just before

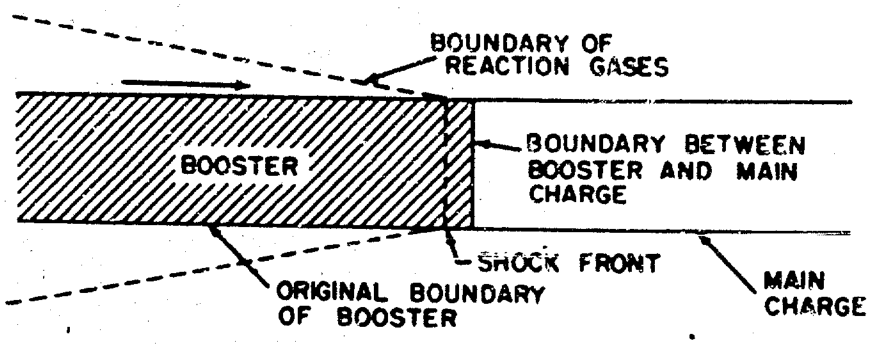


Figure 7–10. Profile of the Detonation Wave of a Cylindrical Booster of Very Large Diameter Crossing the Boundary of a Cylindrical Main Charge of Equal Diameter.

the shock wave crosses the boundary, we may picture the situation as shown in figure 7–10.

At the instant the shock front crosses the boundary into the new material, any one of three situations may arise, as follows:

(*a*) The transmitted shock intensity (and velocity) initially exceed the stable values characteristic of the main charge.

(*b*) The transmitted shock intensity (and velocity) approximately match the stable values characteristic of the main charge.

(*c*) The transmitted shock intensity (and velocity) are less than the stable values characteristic of the main charge.

In case (*b*), the detonation wave will suffer only minor perturbations as it crosses the boundary into the new explosive. In case (*a*), the energy supplied by the decomposition of the new explosive will not suffice to support the too-high velocity. As a result, the velocity will gradually decrease to the stable value for the new material and corresponding changes in P and T will occur at the same time. Once the

new stable values have been reached, the detonation will proceed without further alteration.

In case (*c*), either of two things can happen. If the initial pressure and temperature in the transmitted shock wave are high enough, decomposition of the new explosive will be rapid enough to supply an excess of energy to the slow-moving shock wave, and P, T, and D will gradually increase to the stable values for the new explosive. If, however, the initial pressure and temperature are too low, the decomposition of the new explosive will be too slow to support the shock wave. P, T, and D will therefore decrease until D becomes sonic. The detonation has "failed" although some of the main charge may have undergone rapid decomposition ("partial detonation") or burned ("deflagration") in the process. Stable, low-rate "partial detonations" of high explosives have not been observed to occur **under conditions normally encountered in the typical main charges of mines, torpedos, etc.**

Conditions (*a*) and (*c*) above are commonly referred to as "over-boostering" and "under-boostering," respectively.

The reaction zone length, "a," is the important parameter in these considerations. It largely determines how easily and how rapidly stable detonation may be established in the main charge. The shorter the reaction zone length, the more rapidly and the more easily stable conditions are reached in the new explosive.

Unfortunately, the present status of detonation theory plus the available knowledge of "a" for the various explosives does not permit the quantitative treatment of practical problems. It is probably a correct approximation that the reaction zone lengths of the various explosives become longer as the sensitivity decreases. Thus primary explosives have reaction zone lengths which are probably of the order of one-tenth millimeter or less. Materials commonly used as boosters probably have reaction zone lengths of 1–2 millimeters, while for the most insensitive high explosives, such as Amatol, the reaction zone length may be as much as 5 millimeters or more. We shall not be far wrong, then, if we use the booster sensitivity indices as a rough measure of the relative reaction zone lengths of the various explosives.

The situation illustrated in figure 7–10 has been somewhat idealized, and a typical booster-main charge combination may differ from it in several ways. First, the detonation wave may be curved. If a charge is initiated at some point on its surface (fig. 7–11), the detonation wave will spread from the point of initiation as a spherical wave. The surface of the wave front is expanding as its radius of curvature increases, and, because the reaction zone is of finite length, the expand-

ing wave is at any instant fed by a smaller energy than the plane wave illustrated in figure 7-10.

As a result, P, T, and D in the shock wave are all lower than the stable values for the plane wave, and "a" itself is larger because the lower pressure and temperature in the shock front result in a lower rate of decomposition of the explosive. The smaller the radius of curvature of the wave, and the longer the reaction zone length of the explosive, the greater will be the difference between the instantaneous P, T, and D and the corresponding stable values for the explosive. If the radius of curvature is less than two or three times the reaction zone length, the detonation will, in all probability, fail.

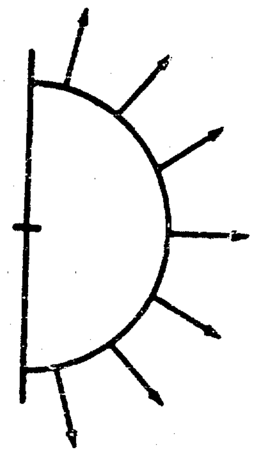


Figure 7-11. Detonation Wave Obtained When a Charge Is Initiated at a Point on Its Surface.

The importance of these considerations from the standpoint of booster design may be summarized as follows:

(*a*) If the radius of curvature of the detonation wave, at the instant it passes into the main charge, is small compared to the reaction zone length of the booster explosive, the intensity of the initial shock wave in the main charge will be considerably less than the stable intensity for the booster explosive, and there is a strong risk that the main charge will be seriously under-boostered in the sense of case (*c*) in the preceding discussion.

(*b*) If the radius of curvature of the initial shock wave in the main charge is small in terms of the reaction zone length of the main charge, the expanding wave may die out.

In the sense of (*a*) and (*b*), just stated, a radius of curvature of less than some five times the reaction zone length may be considered to be extremely risky.

Conformance with these conditions is necessary but not sufficient to insure proper initiation of the main charge. Another way in which

a practical assembly may differ from the idealized situation pictured in figure 7–10 is illustrated in figure 7–12. In this case, a small booster is used to initiate a much larger main charge. The booster is partially imbedded in the main charge, and we will assume that the detonation wave in the booster is approximately plane and traveling with its stable velocity. Now the intensity of the shock which is transmitted to the main charge is directional because of the forward momentum of the product gases of the detonation wave, and is most intense directly in front of the booster as is indicated in figure 7–12 by arrows.

If the main charge is sufficiently insensitive, the less intense side shocks may be insufficient to effect proper initiation of the main

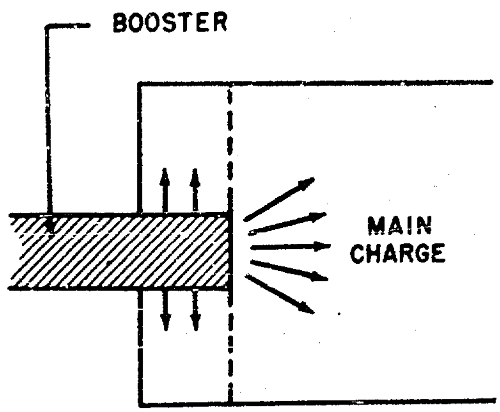


Figure 7–12. Detonation Wave in a Booster Initiating a Much Larger Main Charge.

charge, for, once again, the wave is an expanding one, cylindrically this time, and the reaction zone length of the main charge may be quite large. Consequently if that portion of the main charge enclosed by the dotted line is to detonate properly, the detonation wave spreading from in front of the booster must, in effect, turn around and propagate backwards. Explosives of relatively long reaction zone length show considerable resistance to this type of propagation. If, for example, a TNT charge is cast in the form of a block L and initiated along one leg, as shown in figure 7–13, that portion of the charge which has been shaded in will fail to detonate and may be recovered in its initial state (ref. (2)). If, however, that part of the figure enclosed by the dotted line is filled in, so that the detonation wave may expand gradually, the whole charge will be consumed.

This difficulty is not normally encountered with those explosives commonly used as boosters, as even the weaker side shocks are sufficiently intense to initiate a material of such sensitivity, and, in any

event, the shorter reaction zone lengths of such materials readily permit the detonation wave to turn corners. If, however, a TNT or Explosive D loaded projectile is boostered as shown in figure 7–13, fragmentation may very well be poor at the booster end of the pro-

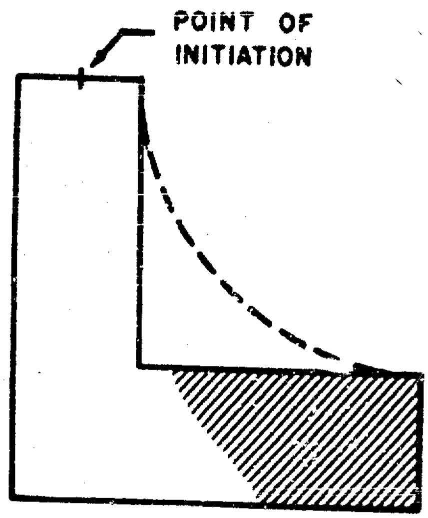


Figure 7–13. Detonation Wave in a TNT Charge Cast in the Form of a Block L and Initiated Along One Leg.

jectile. This difficulty can be avoided as shown in figure 7–14, provided the radius of curvature conditions are met by using a booster whose diameter is large compared to the reaction zone length of the main charge explosive.

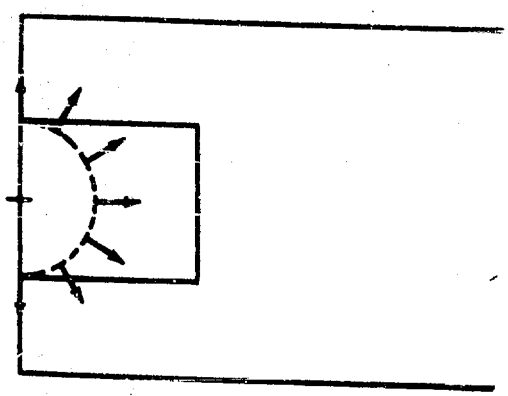


Figure 7–14. Detonation Wave in a Booster Whose Diameter Is Large Compared to the Reaction Zone Length of the Main Charge.

Factors Affecting Booster Output

Effect of booster size. The question of booster size was, of course, considered in the preceding discussion. One or two additional points should be made, however, from a somewhat different viewpoint. We shall consider the two cases:

(*a*) The effect of using a booster that is too large.

(*b*) The effect of using a booster that is too small.

The first case is readily disposed of. Once the booster size exceeds a certain critical size (which depends on a number of factors), little, if anything, is gained by further increasing the size. The performance of the main charge is not improved, and we are, in effect, merely replacing main charge explosive with booster explosive. Whether this results in an over-all improvement of the performance of a weapon depends on the relative performance of the two types of explosive in the weapon in question. For example, if a grossly oversize Tetryl booster is used in an Explosive D loaded projectile, an apparent improvement in fragmentation may very well result simply because Tetryl is a "more powerful" explosive than Explosive D under these conditions.

The consequences of using a booster that is too small may be much more serious, for it may result in very poor performance of the weapon in the region near the booster, or the main charge may fail to detonate. The answer to the question "How large must the booster be for maximum performance?" depends on a number of factors, some of which have already been discussed, others of which are considered under the headings which follow. First, we pause to state three possible conditions:

(*a*) If, in a given munition, we change the main charge explosive to one having a higher booster-sensitivity index than the original explosive, and, if the booster was already of adequate size for the original main charge, then the same booster will, in all probability, be adequate for the new explosive.

(*b*) If, in a given munition, we change the main charge explosive to one having a lower booster-sensitivity index than the original explosive, while using the same booster, the new main charge may be under-boostered unless the original explosive was already over-boostered.

(*c*) If the main charge is capable of maintaining stable detonation, the required booster size does not depend on the size of the main charge.

Although this last statement is undoubtedly correct, there exists a general tendency to increase the size of the booster as the size of the main charge is increased. Within reason, this is probably not a bad

practice, for an over-boostered munition is less likely to fail to function because of poor booster design or placement, or because of some minor booster defect. The larger and more complex the munition, the greater the economic loss should a misfire occur.

Booster composition and density. Boostering experiments (ref. (5)) suggest that the effectiveness of an explosive as a booster, from the output standpoint, is expressed by its brisance, as defined on page 2-12. The relative brisance indices there given have been determined at densities which represent good loading practice; these indices decline sharply as density decreases, as shown by the following data for Tetryl (ref. (8)).

Density	Brisance (TNT=100)
1.59	115
1.52	109
1.42	100
1.36	96

These data illustrate the fact that even an explosive as inherently brisant as Tetryl can easily be made less brisant than TNT by low density loading.

Booster shape (refs. (9) and (10)). If the booster is to be completely external, as shown in figure 7-15, very large and very small ratios of length to diameter are to be avoided for maximum effectiveness. Brisance tests (ref. (5)) indicate that for a given diameter of Tetryl, the maximum effectiveness is obtained when the l/d ratio is about 1.5. Further increases in charge length have no effect. The variation of plate dent with pellet dimensions is shown in figure 7-16. These data were obtained for Tetryl. (It is believed the plates were failing in the 2.5 inch diameter tests, and the dents obtained for these charges may consequently have been unduly high).

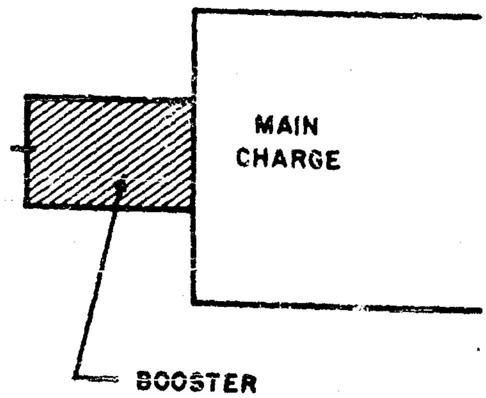


Figure 7-15. Completely External Booster.

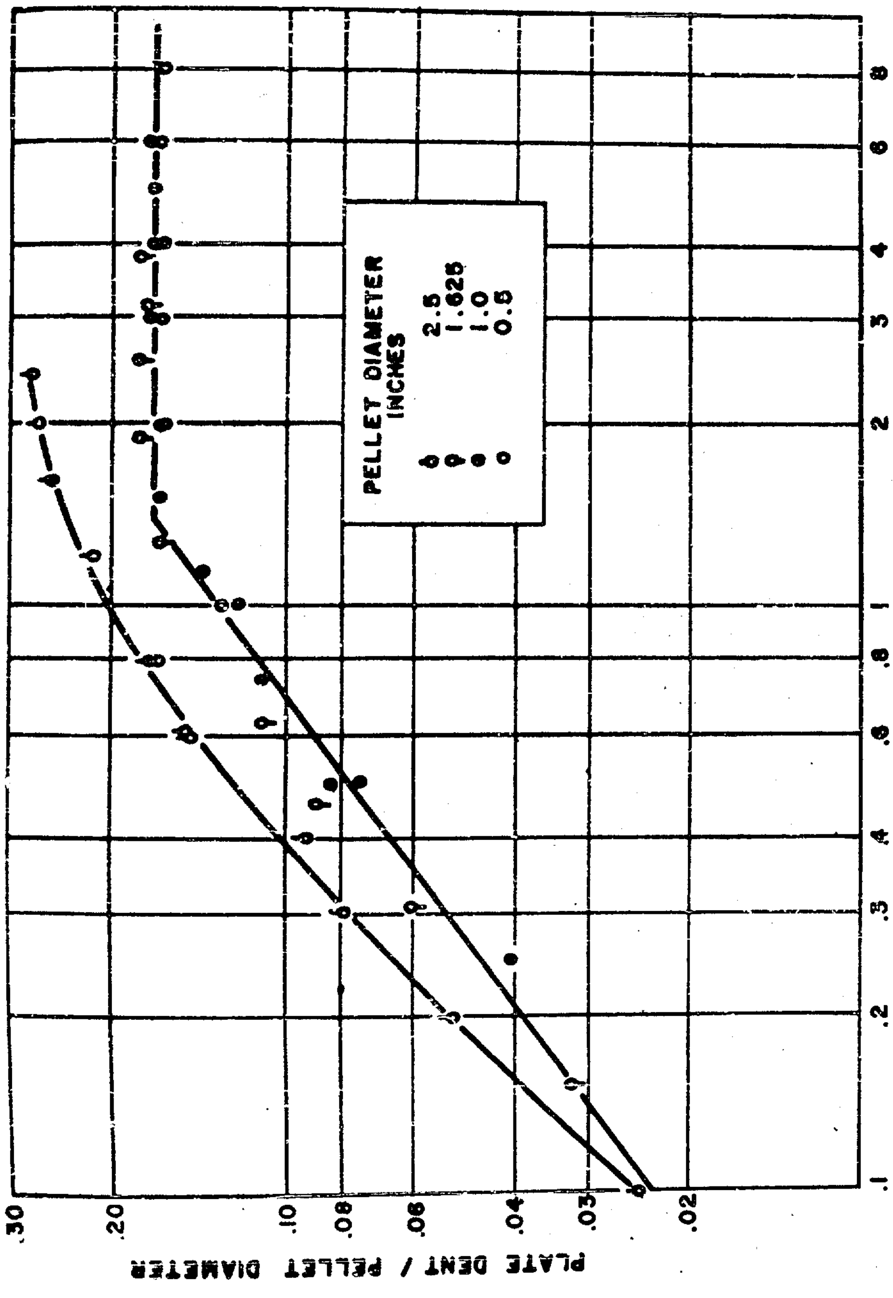


Figure 7–16. Variation of Plate Dent with Pellet Dimensions.

When the booster is to be partially or completely inbedded in the main charge, the situation is considerably different. This case is considered below under the topic "Booster position."

Some experimental work has been performed with boosters of special shapes, such as shaped charge boosters. Such boosters offer no advantage unless it is necessary to place the booster at a considerable distance from the main charge (ref. (11)).

Booster confinement. Side and top confinement of an external booster may be expected to increase the efficiency of the booster provided the confinement is sufficiently rigid, as by a heavy steel surround. Weak confinement has little or no effect.

Granulation of booster explosive. Changes in the granulation of the booster explosive would affect mainly the sensitivity of the booster. (See page 7–13, Effect of Booster Explosive Granulation on Sensitivity.) Little or no effect on output is to be expected.

Ambient temperature. Actual data are extremely meager. Little or no effect would be predicted from the basic theory of detonation for temperatures in the range of -65 to $+160°$ F.

Miscellaneous Factors Affecting the Transmission of Booster Output to the Main Charge

Booster position (ref. (9)). A booster that is partially or completely imbedded in the main charge will, weight for weight, be much more effective than an external booster, particularly if the main charge is sufficiently sensitive to be initiated by the side shocks (fig. 7–12) or if the booster is initiated as shown in figure 7–14. Once again, very small l/d ratios should be avoided. Large l/d ratios can be and frequently are used, however; but the diameter should not be too small—preferably not less than one inch or thereabouts, depending on the reaction zone length of the main charge. For explosives which are difficult to initiate and which maintain stable detonation only with difficulty (such as amatol made from coarse nitrate, Minol and hot-cast TNT), full length boosters, sometimes quite massive, are needed. With the possible exception of Explosive D, no such explosives are in current use by the Navy.

Separation of booster from main charge. Separating the booster from the main charge by very thin metal or other containers, or by very small air gaps, will not seriously reduce the efficiency of the booster. As the thickness of the barrier is increased, the shock transmitted to the main charge will decrease until it will eventually be insufficient to initiate the main charge. Booster sensitivity tests (ref. (5)) suggest that waxes, light metals (aluminum) and plastics (polystyrene) are less efficient barriers (that is, will transmit a greater

proportion of the shock) than the heavy metals (copper) or wood (oak). The booster sensitivity indices are, in fact, approximately the greatest barrier lengths of wax through which an explosive can be initiated with a specified booster under specified conditions. For small gaps, air is about as effective a barrier as aluminum or polystyrene.

Section 4.—References

Parenthetical numbers preceded by the letter "S" are Naval Ordnance Laboratory file numbers.

(1) NDRC Division 8 of OSRD Interim Report PT–25, **Preparation and Testing of Explosives.** August 15, 1944 to September 15, 1944. (S–34430).

(2) OSRD Report 5617, **Initiation Studies on Solid Explosives.** (S–7967).

(3) OSRD Report 5744, **Physical Testing of Explosives, Part II, Sensitivity Studies with the Drop Weight Impact Machine.** (S–7987).

(4) NAVORD Report 87–46, **Table of Military High Explosives,** (S–18135).

(5) NOLM 10336, **The Sensitivity of High Explosives to Pure Shocks.**

(6) NAVORD Report 70–46, **The Stability of Detonation.** June 15, 1946. (S–10775).

(7) NAVORD Report 90–46, **Theory of the Detonation Process.** (S–12635).

(8) OSRD Report 5746, **Physical Testing of Explosives.** (S–8099).

(9) NAVORD Report 6–47, **Minimum Boostering Requirements for Cast TNT Charges.** (S–12337).

(10) DuPont Report dated November 20, 1945, **Booster Requirement for Cast Military Explosives.** (S–8022).

(11) OSRD Report 5629, **Shaped Charge Boosters.** (S–7986).

(12) NOLM 10303 **RDX/Wax Mixtures as a Substitute for Tetryl in Boosters.** June 15, 1949.

Chapter 8

INTERACTION OF EXPLOSIVE TRAIN COMPONENTS

The input and output characteristics of explosive train components are considered in earlier chapters. In attempting to reduce explosive train design to a sound engineering basis, the ultimate objective is to be able to predict with what reliability an explosive train element with a given output will initiate another element with a given input requirement under known conditions of configuration and confinement. In general, such a prediction is not possible at present. However, this chapter summarizes the existing knowledge regarding the interaction of explosive train components. The discussion is limited to cases where one explosive train element is initiated directly by another explosive loaded element and includes the initiation of delays, flash detonators, leads and boosters.

Section 1.—The Initiation of Delays

General

Pyrotechnic delays are initiated by raising the temperature of the initiating end of the delay column to the point at which the delay powder begins to react. The necessary heat may be supplied by any of a number of means including rocket gases, propellant charges, and electrical energy. In most ordnance devices, however, the heat is supplied by a primer, and this discussion will be limited to that method of initiation.

Examples

Numerous examples of the initiation of black powder delays by primers are shown in figures 5–1 to 5–13 inclusive. A typical example of the initiation of a gasless delay column by a primer is shown in figure 5–41 (page 5–52).

Design Variables

The usual requirement of the delay is that it burn through within a specified time after the primer is initiated. This time will not be reproducible and reliable if (*a*) the primer does not reliably initiate the delay; (*b*) particles from the burning primer imbed themselves in the delay column, thus effectively shortening the column; or (*c*) the blast from the primer disrupts the column. The design variables that

affect these aspects of delay functioning are considered in the following paragraphs.

Reliable initiation of the delay. Heat from the primer may be transferred to the delay column by conduction, convection, radiation, or adiabatic compression. While the transfer is normally by a combination of these means, it is probable that radiation is usually the least important. Reliable ignition of the delay is thus facilitated by directing the primer blast at the delay column surface. It has been observed that ignition is more reliable in obturated (nonvented) delays, probably because of the resulting higher pressure which tends to heat the delay surface by adiabatic compression and at the same time tends to prevent expansion cooling of the primer gases. It is concluded that obturation is desirable from the standpoint of delay initiation and that this effect is enhanced by decreasing the free volume available to the primer gases.

Protecting the delay pellet from particle impingement. If the primer is fairly brisant, so that particles are ejected at high velocity, it may be necessary to protect the delay column by suitable baffling. An adequate discussion of baffles is presented on page 5–29.

Preventing the pressure disruption of the column. Baffles tend to protect the delay column from shock pressures. The column can be protected from disruption by static pressure by (*a*) increasing the volume available to the primer gases, and (*b*) by supporting the delay column in a suitable manner. A discussion of these variables will be found in chapter 5, section 1, under the paragraph headings, "Delay body (page 5–18)," and "Pellet support (page 5–23)," respectively. Increasing the free volume or decreasing the confinement makes initiation more difficult, as described earlier in this chapter; accordingly, it is necessary to make a suitable compromise.

Test Procedures

Since it is impossible to predict the reliability of any particular primer-delay combination with any degree of assurance, it is always necessary to carry out suitable tests. The tests should be designed to show (*a*) the reliability of initiation of the delay column, and (*b*) the reproducibility of the delay time.

Reliability of initiation of the delay column. Having chosen the primer, delay column, and supporting inert parts, the ability of the primer to initiate the delay is tested at the lowest temperature at which the device is required to function. If initiation appears to

be reliable, the tests are repeated with reduced primer charges. If initiation is marginal or better with 50 per cent of the normal primer charge, then the initiation should have an adequate margin of surety.

Reproducibility of the delay time. By use of the normal primer charge and the proposed arrangement, the delay time is determined in a number of tests. Erratic delay times may be due to nonuniform primers or delay columns, or to insufficient baffling. If, occasionally, little or no delay action is observed, it is an indication that the delay column is being disrupted by pressure from the primer gases.

Section 2.—The Initiation of Flash Detonators

General

In normal fuze explosive train practice, flash detonators are initiated by the flash, flame, or shock from a primer, a delay column, or another detonator. When another detonator is used, the initiating element may be a small relay detonator placed in the end of a delay column to increase the surety of functioning of the flash detonator. On the other hand, if the design of the fuze is such that the flash detonator is placed at a considerable distance from its actuating element, the latter may be a detonator in order to get reasonable surety of functioning over the long gap.

Examples

An example of a flash detonator initiated by the flash from a percussion primer is illustrated in figure 8–1. This is the arrangement used in the instantaneous base detonating Fuze Mk 28. It will be noted that there is a space of about ½ inch between the primer and detonator. This space has not been provided for any functional reason; it is the space which is occupied by the baffle and delay in the Fuze Mk 21 and other similar fuzes that employ the same basic inert parts.

An example of a flash detonator initiated by the flash from a black powder delay column is furnished by the base detonating Fuze M66A1. The arrangement used in this fuze is shown in figure 8–2.

An example of a flash detonator initiated by the action of another detonator located at a considerable distance is presented in figure 8–3. This arrangement is employed in the point detonating Fuze M51A4. In this instance, the initiation of the flash detonator is probably at least partly due to the impingement of fragments from the bottom of the initiating detonator.

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Design Variables

No basic design data are available that enable one to design scientifically an arrangement for initiating a flash detonator. It would be desirable to be able to predict that with a primer, delay, or detonator having a known output and a flash detonator of a known sensitivity it would be practical to initiate within certain limits of distance, confinement, and misalignment. The lack of adequate input and output

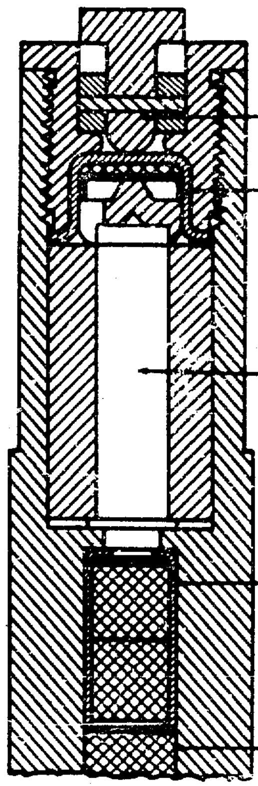

Figure 8-1. Flash Detonator Initiation in Base Detonating Fuze Mk 28.

measuring techniques, together with the formidable number of variables, has discouraged the accumulation of such data in the past. The result is that design has been based on a knowledge of the art, modified by cut-and-try experimentation. From experience gained in this way, it is possible to draw certain qualitative conclusions regarding spatial arrangements and confinement.

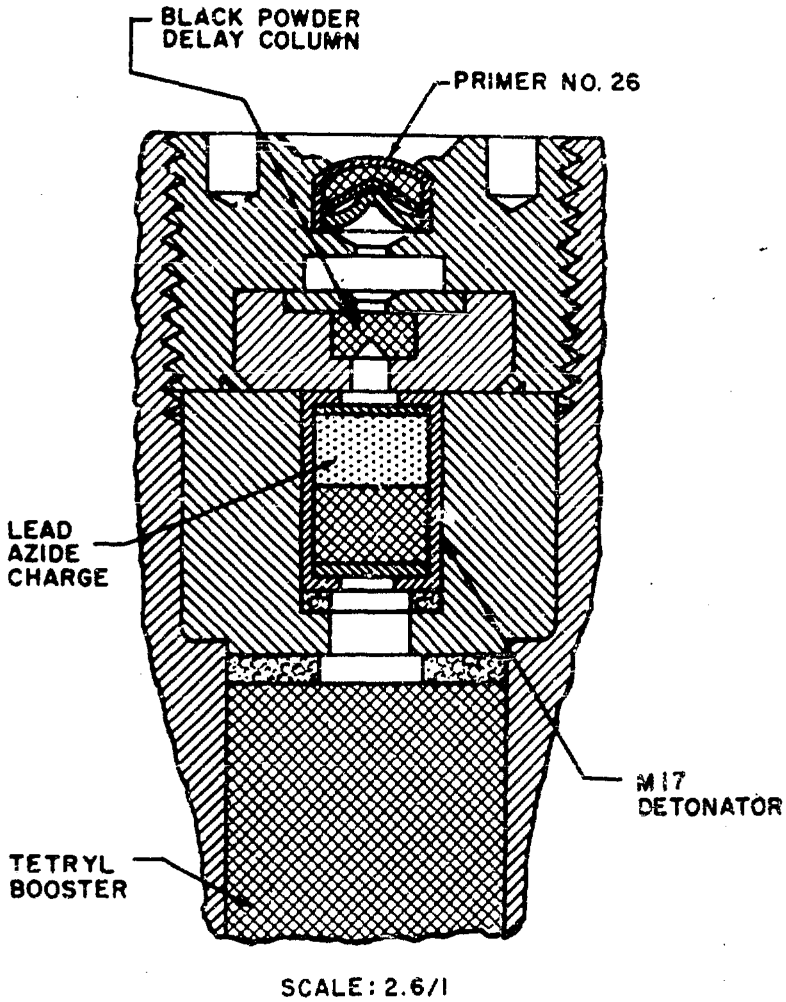

Figure 8–2. Delay-Detonator Arrangement Used in Base Detonating Fuze M66A1.

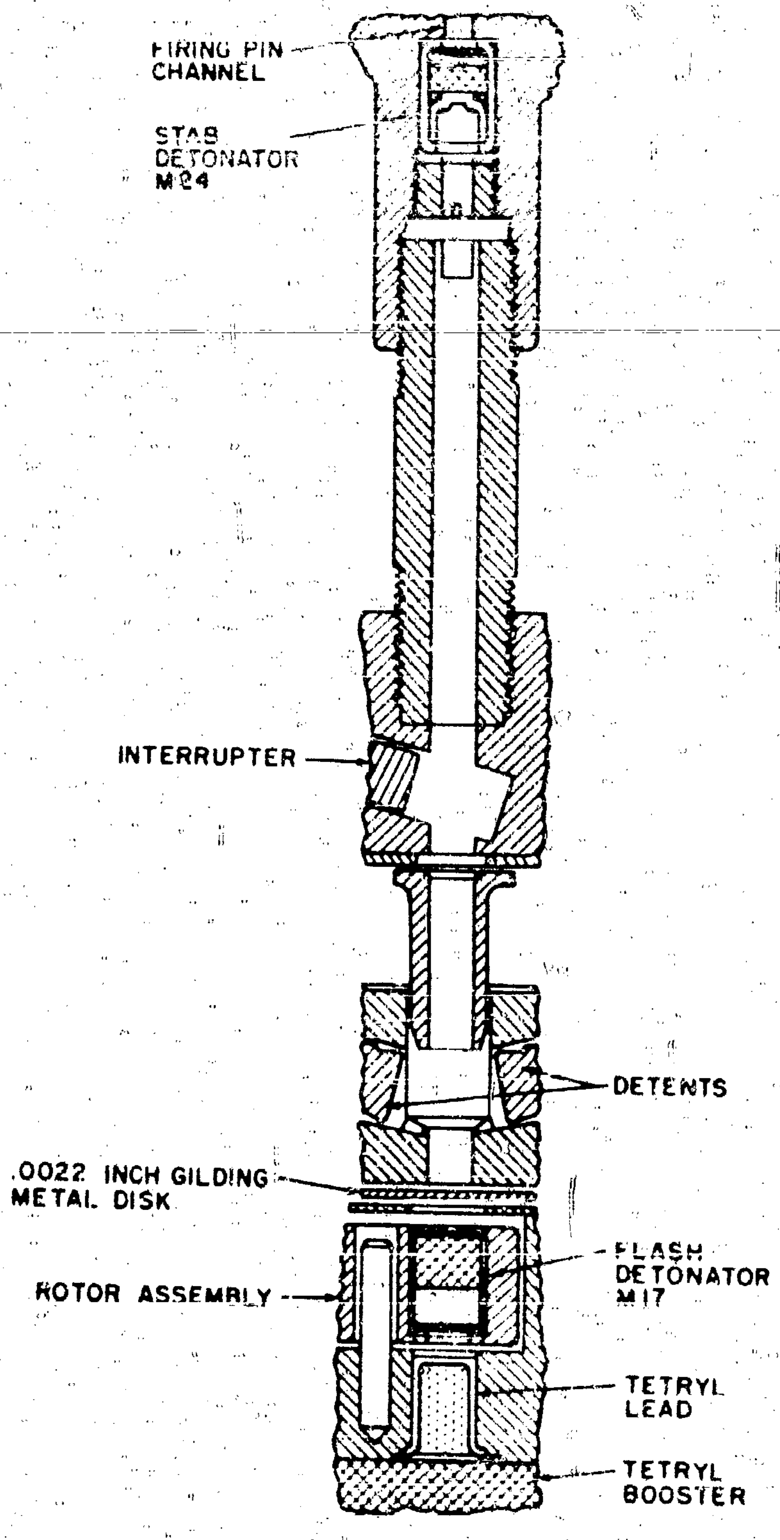

Figure 8-3. Initiation of a Detonator Over a Long Gap as Used in Point Detonating Fuze M51A5.

Spatial arrangements. The ideal spatial arrangement is to place the sensitive end of the flash detonator directly in line with and in close proximity to its source of initiation. It is perfectly feasible, however, to initiate a flash detonator over a considerable distance, as shown in examples just given. Likewise, the detonator may be placed completely out of line with its source of ignition, provided a suitable firing channel is used.

Experience has indicated that for maximum effectiveness the firing channel should be designed so that the hot blast from the source of ignition is directed against the sensitive end of the detonator, then is allowed to move aside so that additional hot gases can come into contact with the detonator. This principle is illustrated by figure 8-4. Work carried out at the Naval Ordnance Laboratory (ref. (1)) showed that with arrangement A, lead azide covered with a 0.003 inch disk could be reliably initiated. With arrangement B, the lead azide could be initiated when covered with a 0.001 inch disk, but not with a 0.002 inch or thicker disk, even though the same primer was used in both arrangements, and the distance between the primer and detonator was considerably shorter in the case of arrangement B. The relatively good performance of arrangement A as compared to that of arrangement B is believed to be due to the fact that the primer gases are directed against and flow by the sensitive detonator surface in the former case, while they are discharged into a blind hole in the latter case.

In spite of the relatively low initiative efficiency of the blind hole arrangement, it is the one commonly used in fuzes because (*a*) it is relatively easy to obtain reliable initiation by using a primer of suitable strength and (*b*) any other arrangement is often impractical because of space considerations.

Confinement. It is generally true that in order to obtain maximum effectiveness from a source of initiation such as a primer, delay column, or detonator, the burning charge should be confined and the gases directed against the sensitive end of the detonator. It is also apparent that as the firing channel is made smaller (confinement increased), the velocity of the hot gases tends to increase. This arrangement increases the effectiveness of the initiation of the detonator up to a point where the decrease in the rate of delivery of hot gases, together with the cooling of the gases in the narrow channel, will cause a decrease in effectiveness. In each case, then, there would appear to be an optimum size of firing channel where maximum effectiveness is obtained.

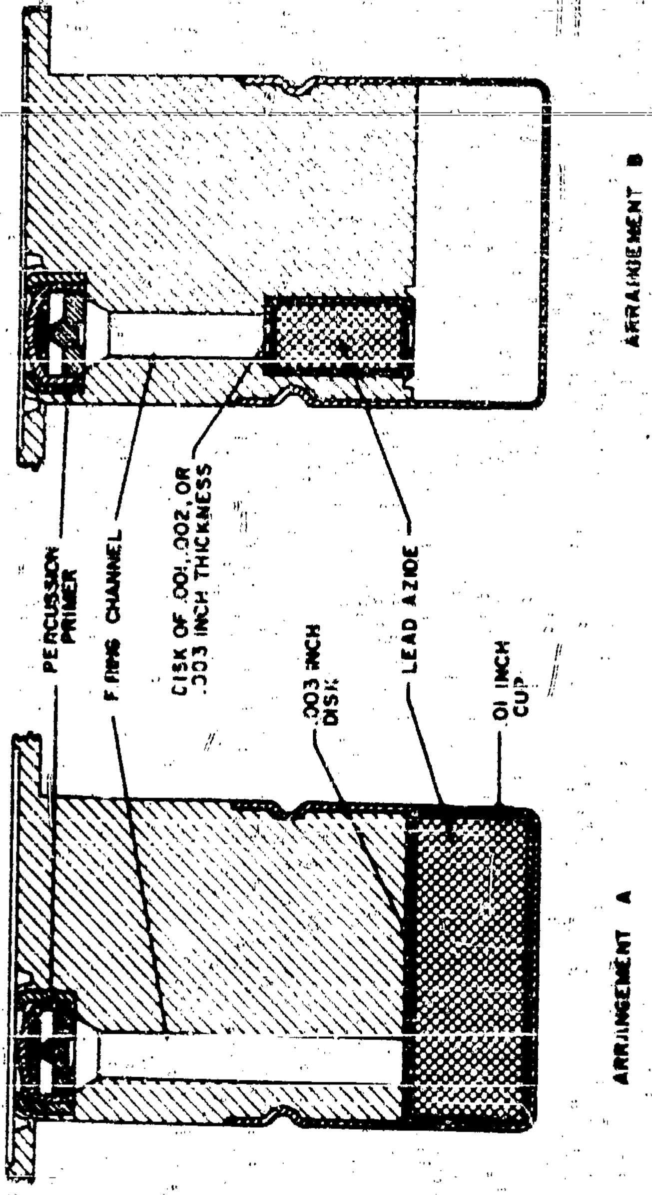

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Figure 8-4. Experimental Modifications of Detonator Mk 8.

In one particular case (ref. (2)), the optimum firing channel size was determined. The test setup shown in figure 8–5 was used in this work. The number of 0.01 inch steel disk that the primer blast would penetrate was used as a measure of its effectiveness as an initiator for flash detonators. The results, presented graphically in figure 8–6, show that Primer Mk 113 (ND–24 type) in the test setup shown in figure 8–5 gives maximum penetration when firing through a channel which is about 0.1875 inch in diameter.

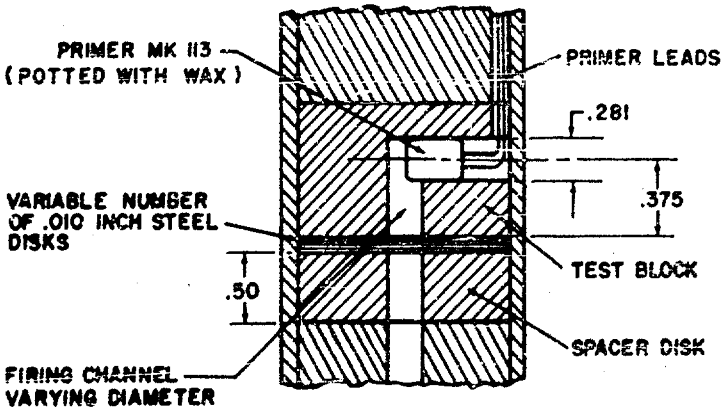

Figure 8–5. Test Fixture Assembly for Determining Optimum Firing Channel Diameter for Primer Mk 113.

Test Procedures

Since the functioning of a flash detonator must be checked, and since several of the design variables can be fixed only by cut-and-try methods, test procedures are of interest. In general, it is desirable to know whether or not the detonator will be satisfactorily initiated by the arrangement being tested, and, in addition, by what margin it functions or fails to function. In general, one of the following three types of tests are employed:

(*a*) The distance between the detonator and its source of initiation is varied to find the distance of marginal initiation.

(*b*) Barriers are placed between the initiator and the sensitive end of the detonator. The thickness of the barrier is varied to find the point of marginal initiation.

(*c*) The amount of charge used in the initiating element is varied to find that required to give marginal initiation.

Method (*a*) appears to be the least reliable of the three methods. It has been shown that, within limits, increasing the distance does not necessarily make initiation more difficult. Method (*b*) has been employed with considerable success. Its principal disadvantage is

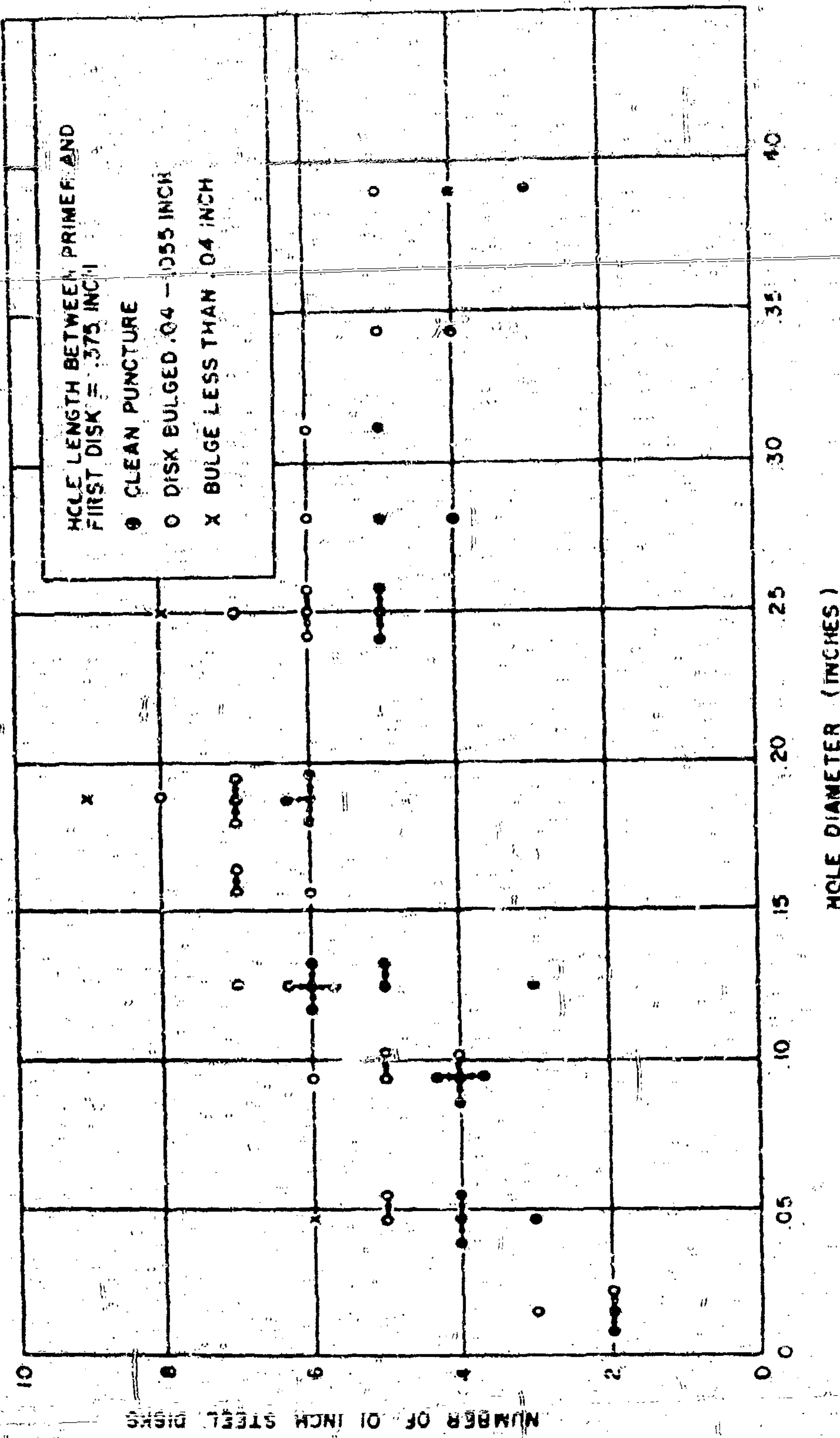

Figure 8-6. Optimum Firing Channel Diameter for Primer Mk 113.

that the results are in terms of an arbitrary scale which cannot readily be converted into terms of surety of functioning.

Method (*c*) is believed to be the most valuable of the three methods. Since the power of an explosive charge is approximately proportional to the amount of explosive it contains, data obtained by method (*c*) gives a direct indication of the margin of surety afforded by a given initiating charge. It has been considered good practice to use an initiating charge which is at least double that which will give marginal initiation.

Low temperatures tend to make the initiation of flash detonators more difficult. Tests should be carried out to make sure that the margin of surety of functioning is adequate at the lowest temperature at which the device is expected to function.

Section 3.—The Initiation of Leads and Boosters

Between the point at which detonation is established in the detonator and that at which it is established in the booster, the detonation must traverse a number of discontinuities. The most obvious of these, from the point of view of mechanical design, are those between the detonator and lead and between the lead and booster. Other discontinuities, such as that between the primary explosive and the high explosive base charge of some detonators, or an abrupt change in the density of a lead, may be more critical in some cases than those between different components.

Some of the discontinuities may be intentionally interposed for the purpose of preventing transmission until the fuze is "armed." Others are unavoidable results of other design considerations. In this section, the factors and conditions which affect this transmission will be considered.

So many variables are involved (explosive properties, dimensions, density, etc.) that, even if a mathematical expression were known relating them all to the probability of propagation, such an expression would probably be too cumbersome for any practical use. The experimental data that exist are fragmentary, although they represent a considerable amount of effort. Certain phases of the problem have been investigated theoretically, but the results of these investigations in general depend for their practical application upon accurate knowledge of values which, at present, are only roughly known. For this reason, this section presents a qualitative discussion of the trends shown by available experimental data in the light of the physical and chemical principles involved. It is not expected that the material

will make possible the successful design of radically new explosive systems on the drawing board. It is hoped that it will help to assure the success of designs involving minor deviations from prevailing practices. It is also hoped that it will be useful in helping to systematize the development of systems involving more radical departures where these are necessitated by mechanical or other considerations. No matter how the design is arrived at, the importance of thorough testing of exact prototypes of explosive systems both for safety and reliability cannot be overemphasized. In such tests, not only explosive but inert components should be duplicated.

General Considerations

The general considerations involved in the transmission of detonation between charges have already been discussed in section 3 of chapter 7, page 7–14. Rather than repeat the discussion, the reader is referred to that section.

On page 7–17 in the discussion of under-boostering, two possibilities are mentioned: (*a*) that the detonation of the under-boostered charge tends to build up to the stable rate; or (*b*) that it tends to die out to sonic velocity. Obviously enough, there must be a set of boundary conditions which divides these two possibilities. This set of boundary conditions might be said to constitute a third theoretical possibility, although such a condition is not stable, since the slightest perturbation will cause it to start an approach toward one of the other two conditions. It is probable that the growth or dying-out process is very gradual in some cases; this assumption explains the "low order" detonation often observed in tests. These boundary conditions are those at which the reaction is just sufficient to maintain the conditions. If, during the reaction time, material and energy are lost radially, then the pressure and hence the temperature in the reaction zone will be lower than if these losses were not allowed to occur. To counteract these losses, the reaction must be more rapid. Thus, where radial losses are possible, the boundary condition involves higher temperatures, pressures, and detonation velocities. Conversely, the stable condition involves lower temperatures, pressures, and velocities. Thus, as the radial losses are allowed to increase, the stable and boundary conditions approach one another until a "critical" condition is reached beyond which detonation will not continue to propagate no matter how vigorously initiated.

As an example, we may consider a cylindrical column of explosive. If the diameter is large compared with the length of the reaction zone, the radial flow of material and energy during the reaction time is negligible. As the diameter becomes smaller, the proportional radial

losses of energy and material increase until a critical diameter is reached. If the explosive column is surrounded by some other substance, the radial expansion will be retarded to a greater or lesser extent by this surrounding material. Thus the critical diameter depends upon the confinement afforded by the surrounding material. For other geometric arrangements there are corresponding critical dimensions.

Although it is highly desirable to keep the dimensions of explosive train components well above critical values, considerations of safety and mechanical design limit the dimensions to that order of magnitude. Thus the propagation of detonation, both within and between the various elements, depends, among other things, upon confinement and those factors which affect the length of the reaction zone. The theoretical consideration of these factors at this point would take more space than would be warranted. Reference (3) discusses many of the factors involved. In the following paragraphs, the measurable and controllable variables at the disposal of the designer are discussed from the point of view of their effects upon the propagation of detonation between charges.

Air Gaps between Donor and Acceptor

Detonation can be transmitted across a gap by any of three agencies: (*a*) the airborne shock, (*b*) the blast of explosion products, or (*c*) the impact of solid fragments of the case of the donor charge. In this section, rather than to refer to various components as detonators, leads, etc., the more general terms of "donor" and "acceptor" are used to signify the charges from and to which detonation may be transmitted.

The effects of (*a*) and (*b*) are virtually indistinguishable, since the shock is almost immediately followed by and continuously supported by the blast within the range where these are important agents of transmission. The effectiveness of the shock and blast might be expected to decrease continuously as the distance increases, but a certain distance is required for the fragments to attain their maximum velocity. Thus, under some conditions a certain amount of air gap is conducive to more reliable and complete detonation.

Reference (4) is a description of fairly exhaustive tests in which the optimum air gap for a certain British explosive train is shown to be about 0.06 inch. Reference (5) discusses indications that, for certain American types of explosive trains, the optimum gap is about twice that value. It is obvious that the optimum gap is a function of—among other things—the materials (both explosive and inert), the size, and the geometry of the donor. Reference (4) shows that the

optimum air gap can also be a function of the confinement of the gap and the density of the acceptor explosive. Also in reference (4), where the effectiveness of the detonator at various standoff distances was determined by the number of metal disks which could be interposed at the face of the acceptor, it was found that the optimum distance, under some circumstances, was a function of the material of these degrading disks. Unfortunately, all the known data regarding these effects are concerned with specific explosive systems and are of such a fragmentary and dispersed nature that the derivation of even the most approximate quantitative principles is not feasible.

The transmission of detonation by the impact of fragments, in addition to introducing this optimum distance for reliable and complete detonation of the acceptor, substantially increases the maximum gap across which detonation can be transmitted, the critical gap. The term "critical gap" as here used applies to an individual combination of donor and acceptor. Such a value cannot, of course, be measured. The measured values quoted here are "mean critical gaps" for groups of combinations which are as similar as it is practical to make them. The mean critical gap is that at which 50 percent transmission occurs.

In unpublished experiments at the Naval Ordnance Laboratory, a cased detonator transmitted detonation across a gap of 0.750 inch to 1.00 inch while the critical gap for an almost identical bare-ended donor was about 0.15 inch. Acceptors for both tests were identical and both donor charges were very highly confined radially, so that the radial confinement of the cased charge was not appreciably different from that of the bare-ended charge. As with the optimum gap, data relating critical gap to the various factors involved are not of a nature which encourages the derivation of quantitative rules.

Although available data on the transmission of detonation by the impact of high velocity fragments leaves much to be desired, two points are clear:

(*a*) When the donor is in direct contact with a thin metal diaphragm (such as the bottom of a detonator cup), the reliability and completeness of detonation of the acceptor may be augmented by the presence of an air gap between the diaphragm and the acceptor.

(*b*) When there is an air gap between the donor and the acceptor, the reliability and completeness of detonation is augmented by the presence of a thin metal diaphragm in direct contact with the donor. Although data regarding the optimum thickness are lacking, experience seems to indicate that this is close to the minimum compatible with manufacturing considerations.

A considerable amount of experimentation has been carried on at the Naval Ordnance Laboratory with bare-ended charges in which the relation between mean critical gap and some of the variables which may be encountered were measured. Although several thousand shots have been fired, the evaluation of all the factors involved is far from complete. The so-called "Bruceton up and down" (Staircase) technique was used with the distance between the donor and the acceptor as the adjustable variable. This technique is discussed in section 1 of chapter 9, under General Remarks on Sensitivity Tests (page 9-29).

The fact that a donor with a metal closure will initiate a given acceptor across a given air gap (point (*b*), page 8-14) is not a positive indication that it will do so across a smaller gap: It is believed, however, that, for bare-ended charges, the critical gap is a reasonable index of the relative effectiveness of transmission. In all the experiments that have been run to date, both the donor and the acceptor charges have been highly confined in metal bodies similar to those shown in figure 8-7. The confining medium of the donor has been brass and that of the acceptor has been copper.

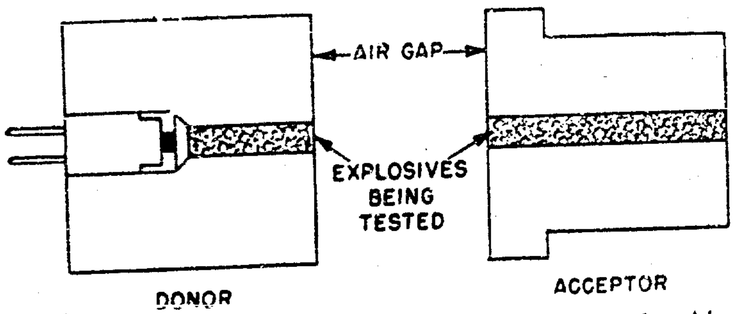

Figure 8-7. Donor and Acceptor Charges Highly Confined in Metal Bodies.

The completeness of detonation of the acceptor has been judged by the expansion of the diameter of the hole in the acceptor receptacle at the end away from the donor. This method is admittedly arbitrary but, for that matter, so is almost any other criterion that can be readily applied. The data obtained in these experiments are plotted in figures 8-8, 8-9, 8-10, 8-11, 8-12. The data from which a number

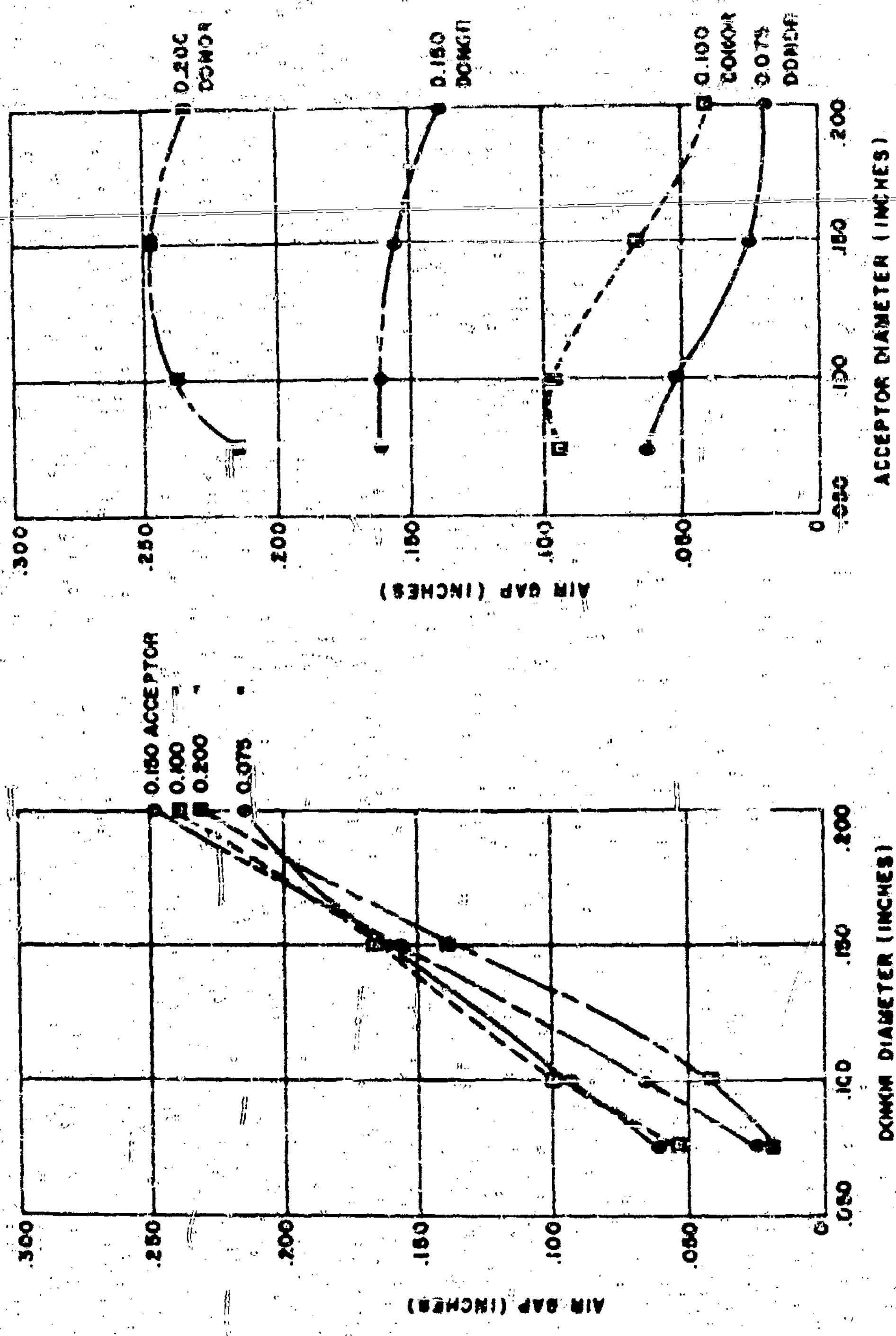

Figure 8-8. *Critical Gap as a Function of Column Diameter.*

of the points were obtained have been analyzed statistically and, in general, the gap for 99.9 percent firing (95 percent confidence level) is more than half the mean critical gap, which in turn is more than half that for 99.9 percent failure. The actual spread between these points is probably considerably less than that just stated, but the small sample sizes and unavoidable inhomogeneity of samples and test conditions both tend to increase the spread of this kind of

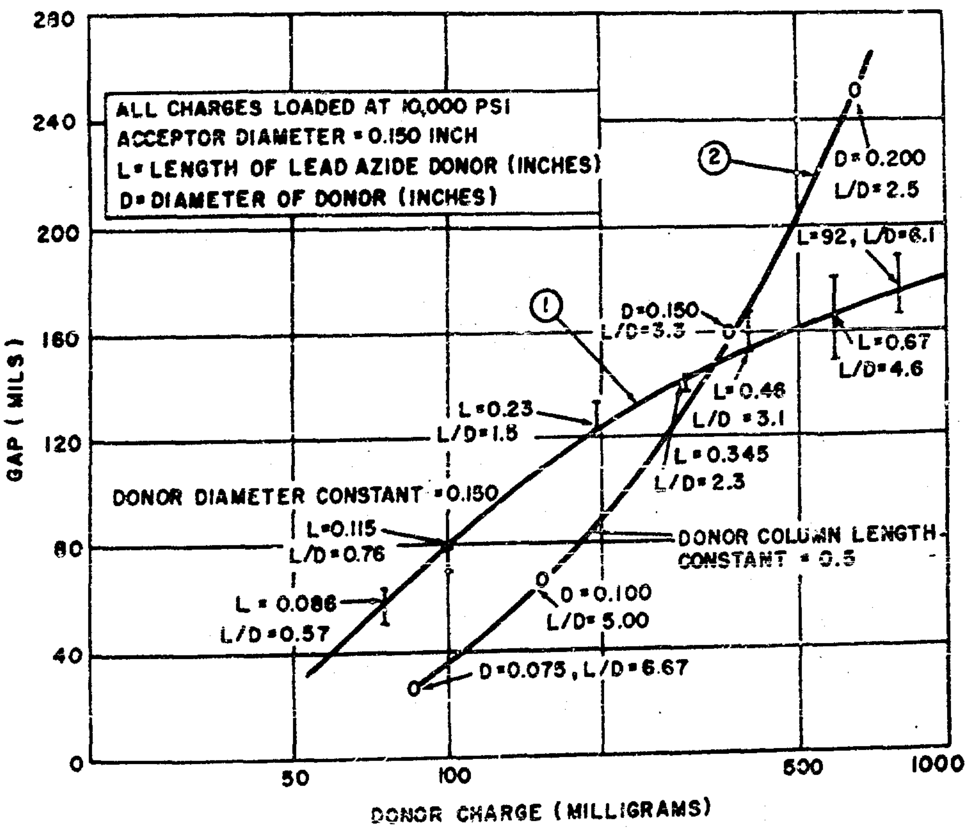

Figure 8-9. Critical Axial Air Gaps Across Which Detonation is Transmitted Between Lead Azide and Tetryl.

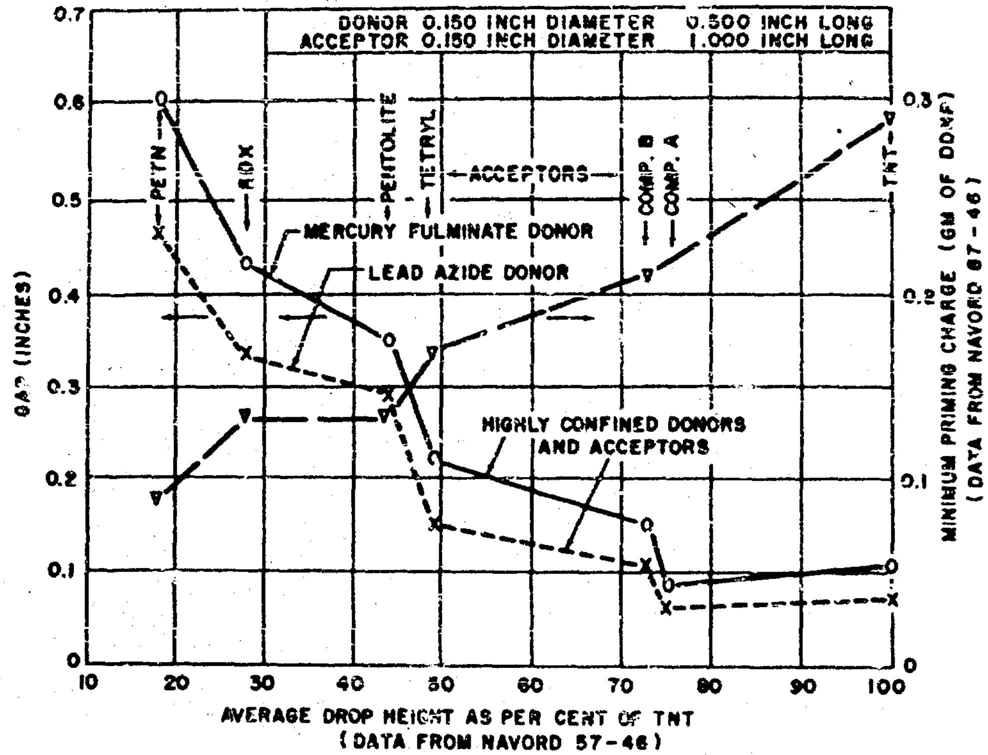

Figure 8–10. Minimum Priming Charge and Gap for Critical Propagation vs. Impact Sensitivity.

estimate. The physical and design significance of these curves will be discussed in some of the following paragraphs.

Diameter effects. Data obtained with various diameters of donors and acceptors are plotted in figure 8–8. All donors in this test were approximately 0.50 inch long columns of lead azide loaded at 10,000 psi. All acceptors were 1.0 inch long columns of tetryl loaded at 10,000 psi. As might be expected, the most notable trend is the direct relationship between donor diameter and gap. The relationship between acceptor diameter and gap is more complicated. Unfortunately, the range covered is too limited to give complete curves for any of the donor diameters used, but it is apparent that each curve reaches a maximum at a point where the acceptor diameter is somewhat smaller than that of the donor.

This phenomenon can quite readily be explained in terms of radial losses. The radial losses of a small column to the surrounding material are larger in proportion to the chemical potential energy available, accordingly, a smaller column must be more vigorously initiated than a larger column. On the other hand, if an impinging shock front strikes only a small fraction of the face of an explosive column, initiating detonation of the affected area only, the radial

losses to the surrounding explosive will be greater than they would be to a denser confining medium such as steel.

As can be seen in figure 8–11, these relationships are affected by variations of other conditions such as loading density of both donor and acceptor. Perhaps the most drastic change in diameter that occurs in an explosive train is that from a lead to a booster. Relatively few data are at hand with respect to this transmission; experiments have been carried on at the Naval Ordnance Laboratory in which long (1 inch plus) confined tetryl leads were used to initiate unconfined tetryl boosters, both pressed at 10,000 psi. The arrangement used in the experiments is shown in figure 8–13. The critical gap with 0.075 inch diameter leads was about 0.04 inch, and that with 0.150 inch diameter leads was 0.145 inch.

Length effects. In explosive trains, many of the elements are initiated by impulses too weak to produce a shock in the acceptor of a velocity equal to the stable detonation velocity. In most detonators, the initial reaction in all probability is usually a deflagration which grows to detonation. Since the detonation velocities of primary explosives are almost invariably lower than those of high explosives (such as tetryl leads), the initial detonation velocities of high explosives initiated by primary explosives are lower than the stable detonation velocities of the high explosives. In all such cases, as has been pointed out, the detonation will build up toward its stable rate or will tend to die out. In practical explosive trains, of course, the detonation grows. After the detonation has reached its stable rate, the "head" of high pressure gas which follows it increases in length. Although the length of this "head" has no effect on conditions in the reaction zone, it tends to support the shock wave which it sets up in another medium, which may be a metal barrier, an air gap, or another explosive. Thus, for several reasons, the length of a column of explosive affects its effectiveness in initiating another column whether it is in direct contact or separated by means of a barrier or gap.

Curve (1) on figure 8–9 shows the relationship between column length and critical axial air gap. It will be noted that even when the length-diameter ratio is as large as 6, additional increments of column length are accompanied by increases in critical gap. Curve (2) indicates that, in the range covered, a given increase in explosive weight is more effective when it is added by increasing the diameter than when it is added by increasing the length. To put it another way, the optimum length-diameter ratio from the point of view of initiating efficiency is apparently considerably below the range of 2/1 to 4/1 which is the practice in Navy detonators.

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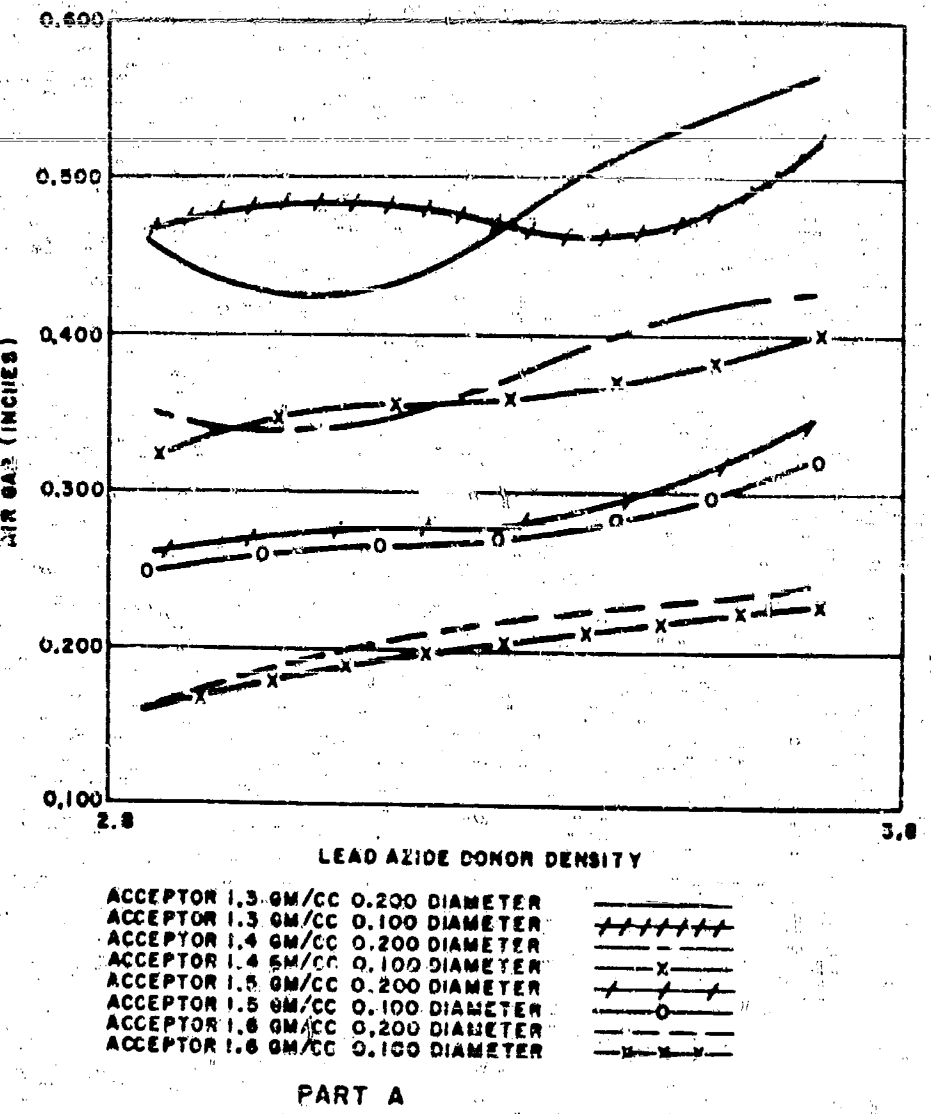
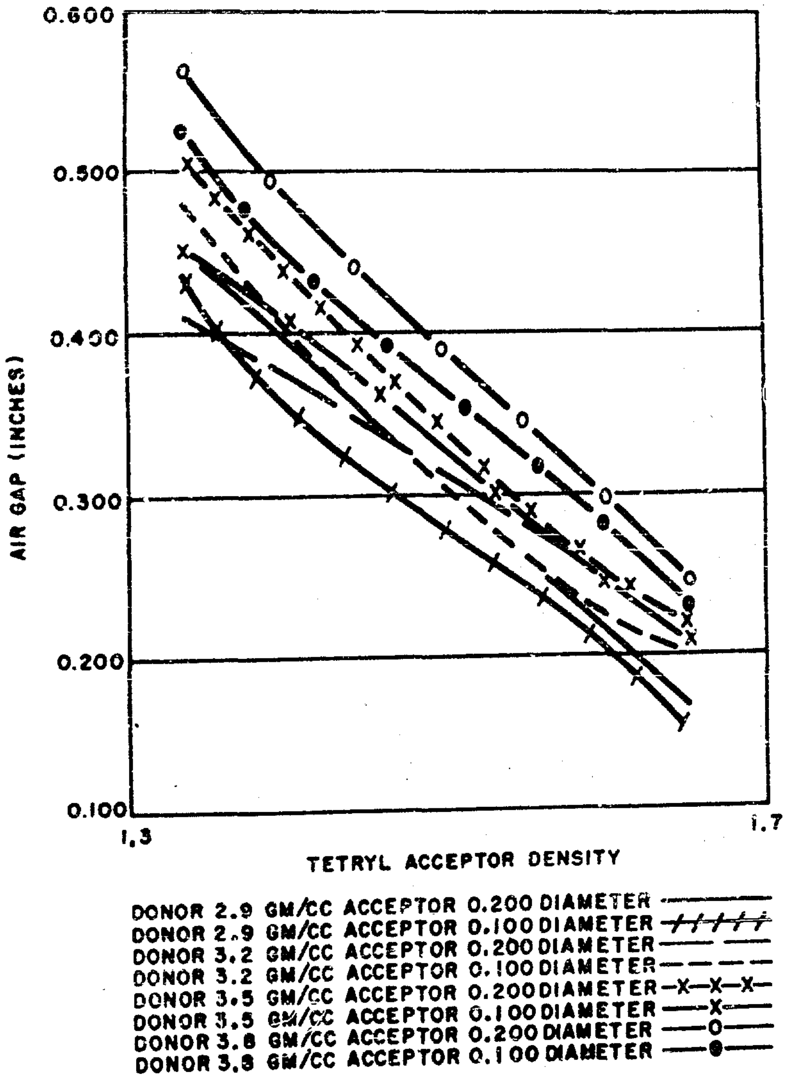
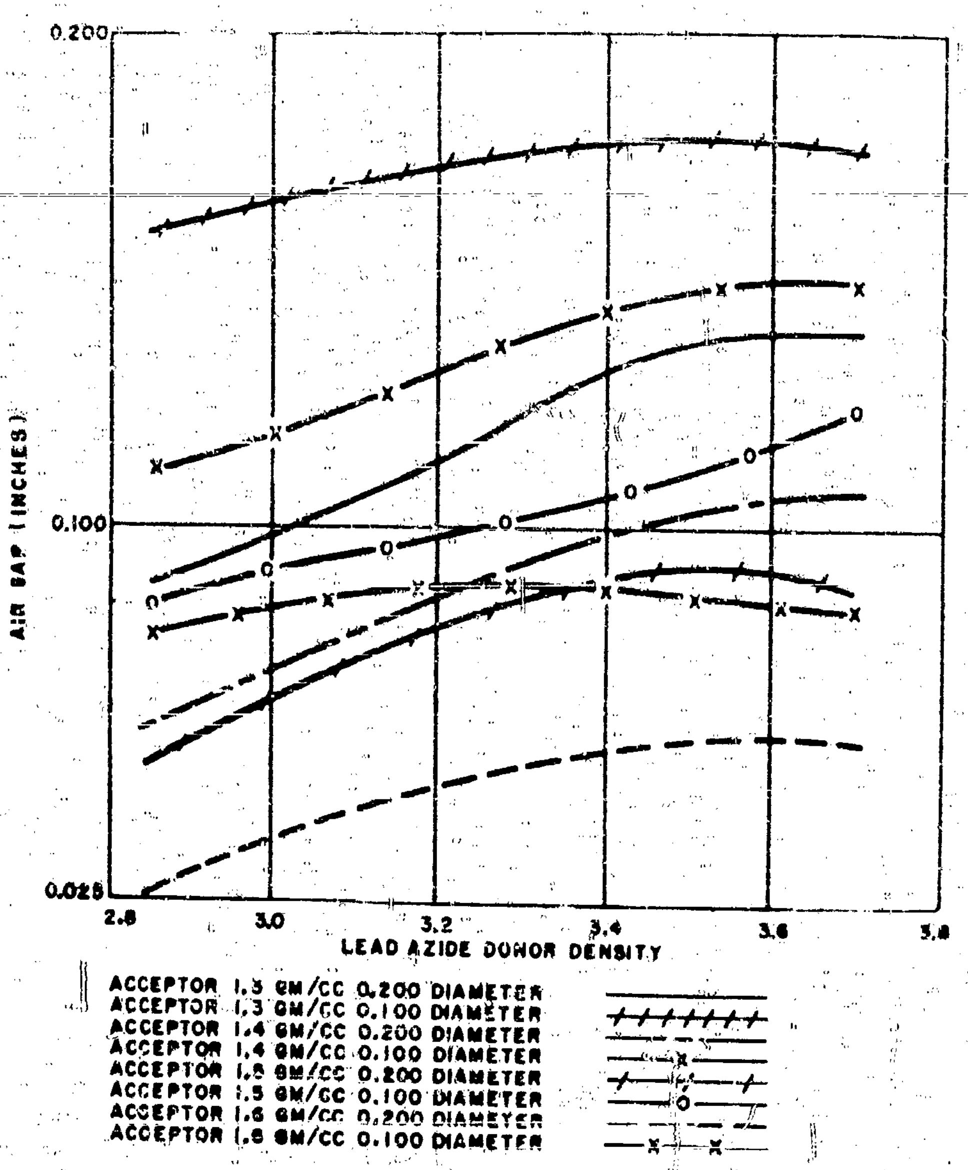


Figure 8-11. Part A. Critical Gap as a Function of Density: 0.200 Inch Diameter Lead Azide Donors, 0.100 Inch and 0.200 Inch Diameter Tetryl Acceptors. See Part B.



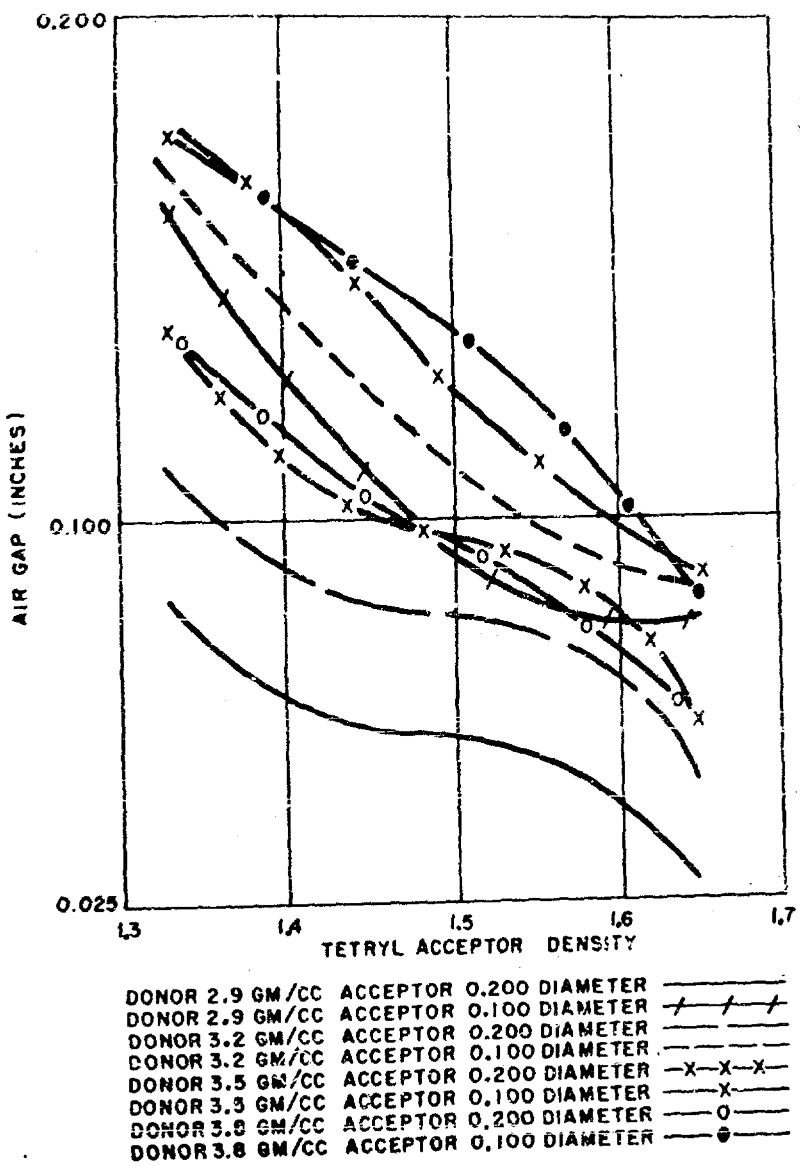
PART B

Figure 8–11. Part B. Critical Gap as a Function of Density. See Part A.



PART A

Figure 8-12. Part A. Critical Gap as a Function of Density: 0.100 Diameter Lead Azide Donors, 0.100 Inch and 0.200 Inch Diameter Tetryl Acceptors. See Part B.



PART B

Figure 8-12. Part B. Critical Gap as a Function of Density. See Part A.

This type of efficiency however, is not necessarily the controlling factor in explosive train design. For example, where a shutter mechanism is to be used as a safety device, less movement is probably necessary for a given degree of safety with a long, slender detonator than with a shorter, stouter detonator of the same initiating effectiveness. The curves on figure 8-9, as noted, are for lead azide donors and tetryl acceptors. It is quite probable that the optimum length-

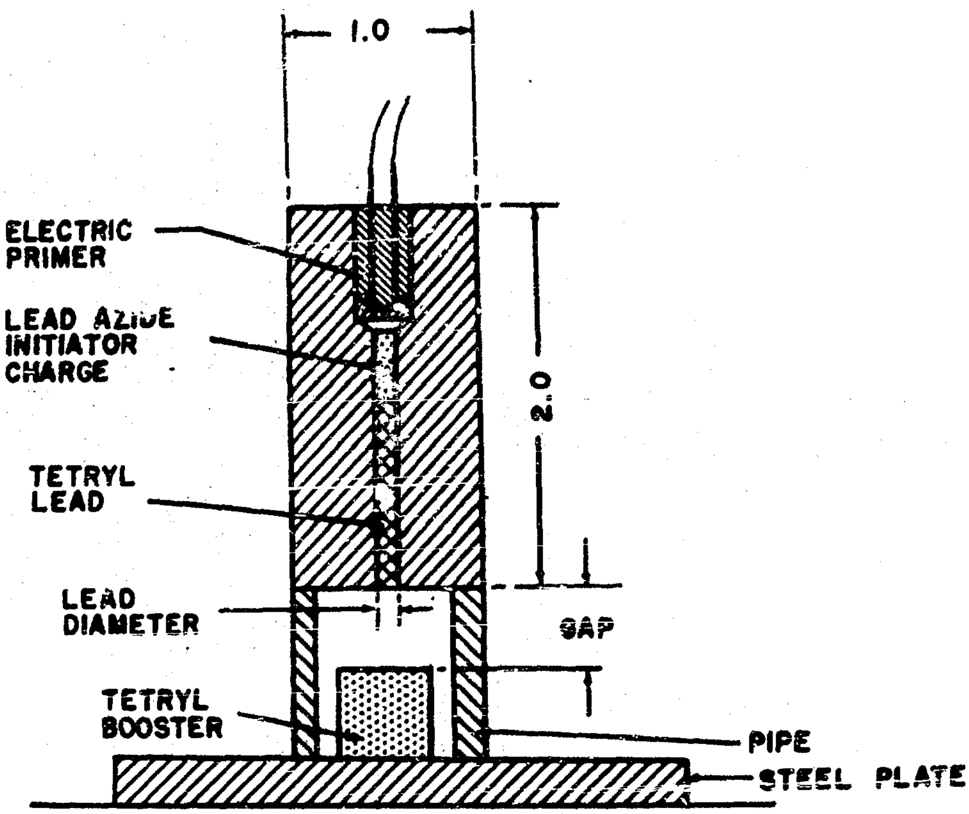


Figure 8–13. Arrangement Used in Lead to Booster Experiments.

diameter ratio for other primary explosives, such as mercury fulminate, which are not as quickly detonated as lead azide, is somewhat larger than that for lead azide.

The relation between the length of a tetryl lead and its output is a function of the vigor with which it is initiated. Although no quantitative data are available regarding these relationships, it is a matter of common observation that holes in which small columns of tetryl have been fired almost invariably taper from a small diameter at the initiated end to a larger diameter at the far end. It is reasonable to believe that the initiating effectiveness of a detonation increases with its destructive power.

Effects of variations of explosive materials. On figure 8–10, critical gaps obtained using various high explosives as acceptors are plotted against the drop sensitivity of the same explosives. It will be noted that the initiation sensitivity and the impact sensitivity of the various explosives are in as good agreement as can be expected with sensitivity tests. It would seem that the dream of discovering an explosive which is sensitive to initiation by means of another explosive yet mechanically insensitive will probably remain a dream. On figure 8–10, the larger gaps obtained with mercury fulminate donors than with lead azide are mainly due to the higher loading density of the fulminate. Both materials were pressed at 10,000 psi, which gives a density of approximately 3 grams per cc for lead azide and a density of approximately 3.6 grams per cc for mercury fulminate.

Density effects. The densities at which both the donor and the acceptor are loaded have considerable effect upon the probability that detonation will be transmitted between the two charges. The available energy, the pressure, and the velocity of stable detonation of a solid explosive increase with the loading density. The pressure and velocity associated with metastable (boundary) detonation also tend, in general, to increase with loading density. Thus the initiating power of any given explosive increases as the density increases unless conditions are such that the higher density results in marginal initiation and a consequent reduction of the length of column which detonates at the full stable rate. In primary explosives, a similar reduction in effective column length may result from the increasing reluctance of explosives to effect the transition from burning to detonation as the loading density is increased. Explosives exhibiting this effect in its extreme are said to be "dead pressed".

The sensitivity of explosives might be expected to increase with per cent of voids for two reasons: (*a*) as the voids in an explosive increase, a shock of a given pressure can do more work per unit mass in compressing the material, thus raising it to a higher average temperature; (*b*) the increasing inhomogeneity of the materials tends to increase the nonuniformity of heat distribution with the result that the hottest areas may be well above the average temperature. This latter effect has two opposing results, the higher temperature in some spots improves the probability of initiation, while the lower temperature at other points increases the time required for complete reaction (lengthening the reaction zone), allowing more time for radial losses. The first effect, while quite applicable when the initiating shock is transmitted to the explosive through air or some other gas, becomes much more complicated when the shock is transmitted to the explosive from a less compressible material, in which case the

intensity of the transmitted shock depends upon the matching of acoustic impedances of the transmitting medium and the explosive. Where detonation is transmitted by means of fragment impact, practically all of the kinetic energy of the fragment is transmitted to the explosive and the concentration of the energy depends upon how quickly the fragment is stopped. This phenomenon would tend to make the apparent sensitivity increase with the density of the explosive.

With so many variables involved, the relation between acceptor density and the probability of transmission of detonation is quite complex. Unfortunately, experimental data are available for only a few of the many possible combinations of the variables involved. On figures 8–11 and 8–12 are plotted critical air gaps obtained with various combinations of two donor diameters, two acceptor diameters, and four densities of each charge. Both donors and acceptors were bare ended in these experiments. It will be noted that the gaps tend to increase with increasing donor density and to decrease with increasing acceptor density. The experiment discussed in reference (4) indicates that the maximum sensitivity as measured by the thickness of a steel barrier through which a tetryl lead could be initiated by means of a certain British type of detonator reached a maximum when the density of the tetryl was about 1.35 grams per cc. When copper was substituted for steel or when an air gap was introduced between the detonator and the degrading disks, this optimum density apparently increased, and in many tests the highest apparent sensitivity was obtained with the highest density used (1.65).

Figure 7–8 (page 7–12) shows the effect of density on the initiation sensitivity of several explosives as measured by the booster sensitivity test, using the arrangement shown on page 7–10. It will be noted that although the sensitivity of tetryl and TNT increases with percent of voids, that of Pentolite and Composition A is nearly independent of density. The reason may be that the last two explosives are both mixtures of sensitive high melting point materials with lower melting, less sensitive materials. The most probable form that they would take would be particles with sensitive cores and insensitive surfaces. Thus the high temperature areas resulting from the inhomogeneity of the less dense charges are at the less sensitive parts of the explosive grains.

Particle-size effects. Where the inhomogeneity of pressed granular explosives results in local "hot spots," as just discussed, the time required for the reaction to propagate from the hotter to the cooler areas is dependent to some extent upon the distances separating these areas. Under these conditions, then, the reaction zone length increases with the particle size. If the particle size distribution is such as to improve

packing efficiency, it reduces the number of grain contacts per unit volume for any given density. The resulting increase in average distance between points of contact also tends to increase the reaction zone length.

In reference (3) the relation of these effects to the stability of detonation is discussed in more detail than is warranted at this point. Reference (3) quotes experiments wherein it was found that a mixture of ammonium picrate of two particle sizes in the proportions conducive to the best packing efficiency failed to support detonation under a certain condition of diameter, confinement, and density whereas each of the two components of the mixture by itself would detonate under the same condition.

No quantitative data regarding particle size effects are at hand which apply specifically to explosive train design. However, in the early stages of the gap tests described in other paragraphs of this section, an inadvertent change in the particle size and particle size distribution of the tetryl used for acceptors caused a substantial change in the results. Since that time, all tetryl used has been of a size which passed through a U. S. Standard number 35 screen and was held on a number 45 screen. Investigations of particle size effects are projected.

Confinement effects. As pointed out earlier, radial losses of material and energy result in a lower stable detonation velocity and a higher boundary detonation velocity. Plainly then, anything which reduces these losses will increase both the initiating effectiveness and the effective sensitivity of an explosive column. The explosive components of explosive trains are surrounded by solid nonexplosive materials, usually metals. Although the designer may think of these materials principally as a means of mechanical support, they are so important to the functioning of the explosives that a majority of fuzes might be rendered inoperative or, at least, quite unreliable by the injudicious substitution of materials in those parts into which the explosives are loaded.

The propagation rate of an explosive reaction, be it a detonation or a deflagration, is a direct function of the pressure in the reaction zone: in the case of detonation, for reasons discussed earlier; in the case of deflagration, because the rate of heat transfer between the product gases and the unreacted solid is directly related to the pressure. Anything which retards the escape of the product gases will cause an increase in the pressure and a consequent increase in the propagation rate. The characteristics of the container of such a reaction which are most important in retarding the escape of the product gases vary with the pressure, propagation rate, and rate of production of gases,

all of which are closely interrelated. If a reaction is very slow and the pressure low, the important characteristic of the container is its continuity, or the absence of leaks. For somewhat faster reactions, the importance of small leaks decreases since the rate of gas production quickly exceeds the leakage rate; but since the pressure is higher, a much stronger container is necessary to maintain a constant internal volume. Finally, under conditions of stable detonation, the pressure is so high that even the strongest metals are too weak to have any confining effect except that due to inertia. The reaction time here is so short that the inertia of the product gases, retarding their expansion, is sufficient to maintain pressures of the order of millions of pounds per square inch independent of any surroundings, except where the diameter is very small. For small diameter columns, the stable detonation velocity can be affected by the confining medium.

It might be concluded, from the proposition that inertia is the important factor in confining a detonating explosive, that the confining effect of various materials should be proportional to their densities. However, it is not quite so simple. With a little consideration, it becomes plain that only that material which has been affected by the detonation within the reaction time can contribute to the confinement of the reaction. It is plain that only that material which has been reached by the shock is affected. The mass of this material is thus a function of both the shock velocity and the density. Some measurements have been made of the velocities of shock waves in metal plates in contact with detonating explosives. Some of these values are tabulated below with the densities, the products of the density and the velocity (acoustic (shock) impedance), and values for the function

$$\frac{P_e}{P_m}\sqrt{\frac{D_e^2}{D_m^2}-1},$$

where P_e is the density of the explosive and D_e is the detonation velocity of the explosive.

TABLE 8-1.—*Shock Characteristics of Metals*

Metal	Shock velocity D_m (meters/sec)	Density ([illegible])	Acoustic (shock) impedance (millions of gm/cm² sec)	$\frac{P_e}{P_m}\sqrt{\frac{D_e^2}{E_m^2}-1}$
Steel	[1] 5240	7.85	[1] 41.1	[1] 0.216
Copper	5350	8.90	47.6	.193
Aluminum	6850–7400	2.70	10.8–18.2	[2] .097–.256
Lead	2745–3020	11.30	31.0–34.1	.348–.372

[1] It will be noted that the shock velocity given for steel is almost exactly the velocity of sound in this metal. It has not yet been definitely established that the true shock velocity is not much lower and thus masked in the measurements.

[2] The large range of these values for aluminum is attributable to the extreme sensitivity of this function to the values obtained for the shock and detonation velocities when these values are close together. It is quite possible that errors in these measurements account for most of the spread.

The expression $\frac{P_e}{P_m}\sqrt{\frac{D_e^2}{D_m^2}-1}$ is proposed in reference (3) as an inverse function of the effectiveness of a material as a confining medium for stable detonations of small diameter explosive columns. It should be pointed out that the values given in table 8-1 were obtained with flat plates normal to the direction of detonation, and that they were obtained with various explosives. Thus, their applicability to design, if any, is indirect.

The minimum shock pressure for transmission of detonation is much lower than that associated with stable detonation; accordingly, the same considerations do not necessarily apply. Although relatively few data regarding these effects are at hand, one series of tests, using 0.10 inch diameter lead azide donors and 0.10 tetryl acceptors both pressed at 10,000 psi, gave the results shown in table 8-2 when the confining medium was varied.

TABLE 8-2.—*Effect of Confining Medium on Critical Gap*

Confining medium	Critical gap (inches)	Confining medium	Critical gap (inches)
Steel	0.160	Lead	0.079
Copper	.084	Aluminum	.043

The values for copper, lead, and aluminum line up reasonably well with the acoustic (shock) impedances, while that for steel is quite appreciably out of line, possibly because the pressure associated with threshold firing may be within the range of the strength of steel under conditions of dynamic loading. It would be reasonable to expect inversions of the ordering of the effectiveness of confining media as conditions such as density and diameter are changed.

Experience with fuzes repeatedly re-emphasizes the importance of confinement. In recent tests it was found that in a fuze which had worked satisfactorily when the leads and booster were housed in steel or brass containers, the booster failed to detonate reliably when die cast zinc or plastic containers were substituted. The confinement afforded by the zinc alloy as compared with the brass may have been reduced by porosity as well as by its somewhat lower acoustic impedance.

In the course of the experiments on barriers, discussed later, a rather interesting confinement effect was noticed. It was found that the insertion of a steel barrier between a lead azide donor and a tetryl acceptor actually increased the violence with which the tetryl detonated, as evidenced by its effect upon the copper body into which it was loaded. Apparently the steel is more effective than the pressure

head of lead azide reaction products in retarding the backward expansion of the tetryl.

Another type of confinement is important in connection with the transition from burning to detonation in primary explosives. This transition depends upon the pressure build-up and consequent acceleration of the burning process. Here the times are sometimes long enough and the pressure low enough for the problem to be that of containing a gas at high static pressures. The strength of even a thin walled detonator cup may be important in this case. These considerations can be important in determining the output characteristics of a detonator insofar as they affect the effective column length.

Transverse Displacement

The commonest means of isolating the sensitive elements of an explosive train from the more destructive elements is the displacement of one column so that it is not aligned with another. Even when the elements are so misaligned, shocks of enough magnitude to transmit detonation may be carried through the metal, or gases at pressures and temperatures sufficient to initiate detonation may find their way from the exploded to the unexploded charge. In practice, the variables which affect both of these mechanisms are so complicated that the displacement necessary for safety can be established only by experiments with actual fuze components.

A series of idealized experiments has been made in which the critical transverse displacement was determined for propagation between lead azide and mercury fulminate donors and acceptors of various high expolsives. Figure 8–14 is a diagram of the test arrangement. In figure 8–15 these data are plotted against the axial gaps obtained with the same combinations of explosives. The "s" shape

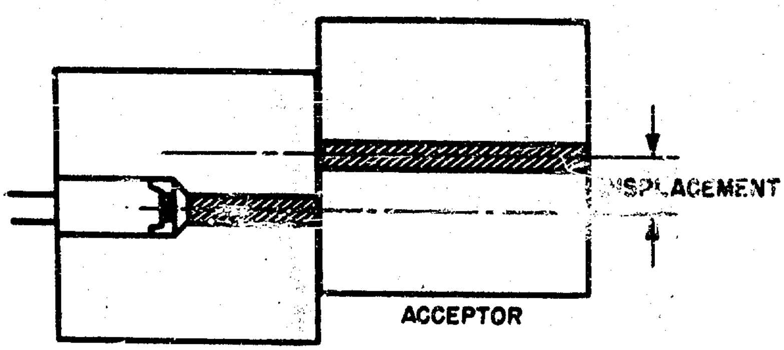


Figure 8–14. Arrangement of Donor and Acceptor in the Transverse Displacement Tests.

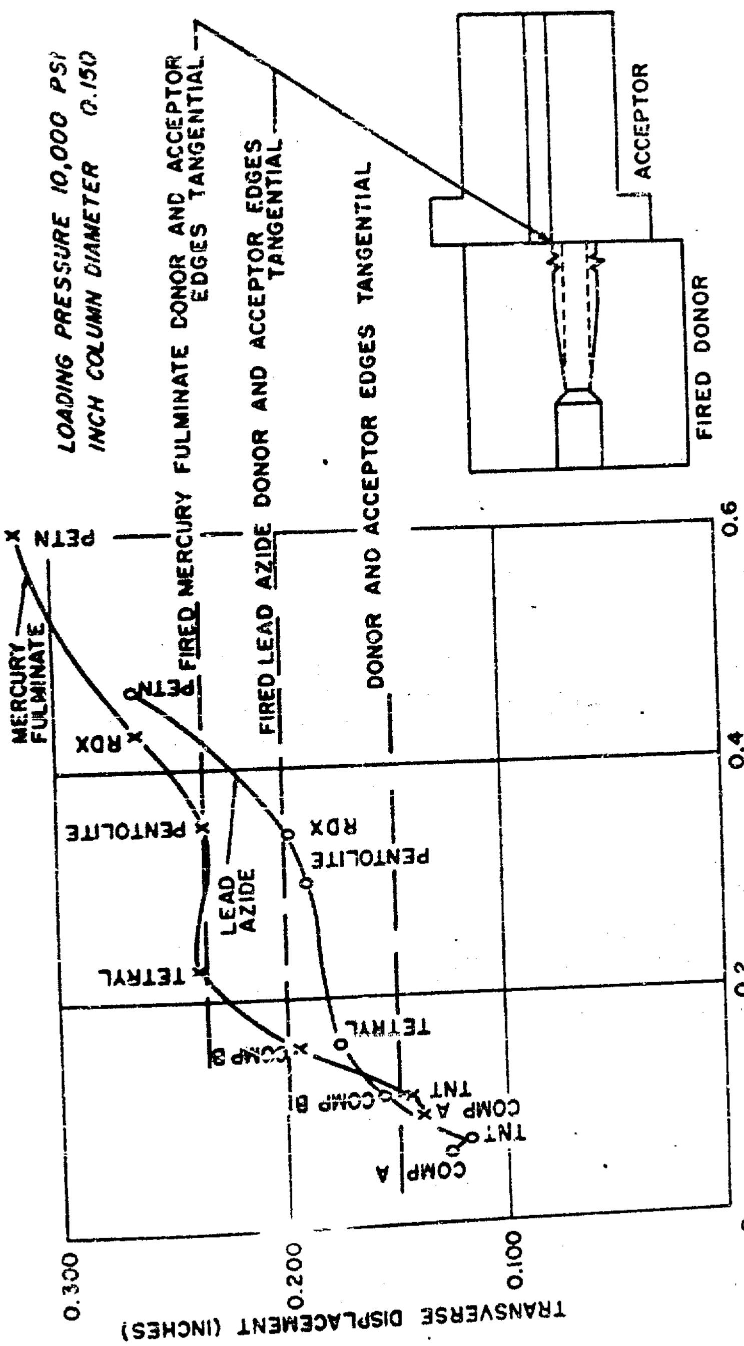
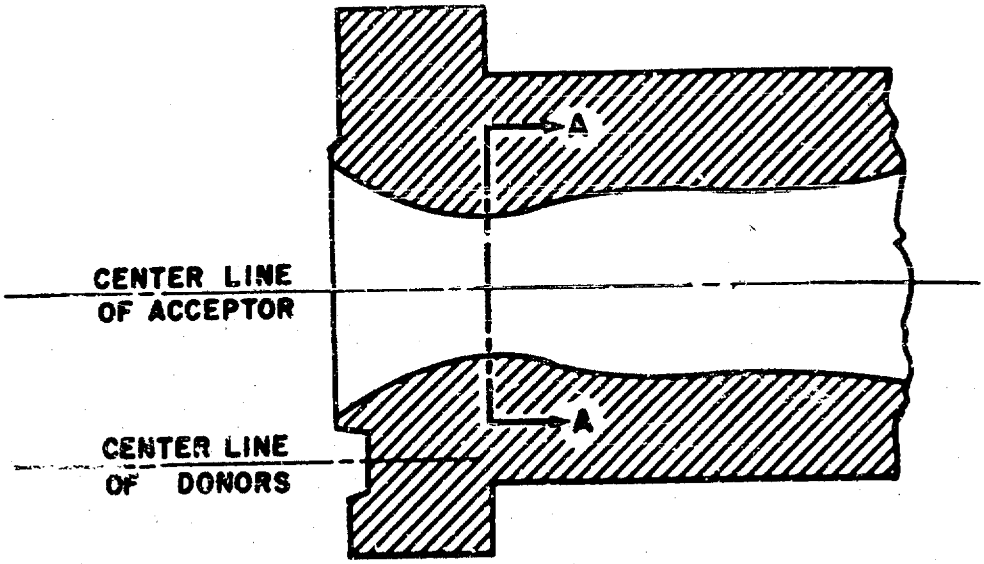


Figure 8–15. Initiation Properties of the Explosive Across Transverse Displacement and Axial Air Gaps.



NOTE: A–A IS LINE THROUGH POINT OF INITIATION

Figure 8–16. Acceptor Initiated by Metal-Borne Shock from Out-of-Line Donor.

of the curves is quite apparently related to the point at which the expanded hole in which the donor charge had been loaded is tangent to the unexploded acceptor.

Evidently the initiation of some explosives, including tetryl, is quite probable when the holes overlap and quite improbable when they do not. This fact suggests that the initiation is accomplished primarily by the hot gases. For more sensitive materials such as RDX and PETN, the metal-borne shock is apparently an important mechanism. Some of the PETN and RDX acceptors were initiated in the interior as evidenced by the way in which the container was deformed, as shown in figure 8–16. These data plotted in figure 8–15, all were obtained using explosives loaded at 10,000 psi in 0.150 inch diameter holes. Experiments with other sizes and loading pressures are projected.

Barriers

When detonation is transmitted between two charges separated by a solid or liquid medium, the transmission may be accomplished either by shock, by gross movement of the barrier, or by a combination of these. In any case, the energy may be lost, as in air shocks, by spherical dissipation and by the irreversible work done by the shock on the material.

An investigation of barrier effects is in progress but experiments to date have been of an exploratory nature. Steel barriers have been substituted for air gaps in experiments similar to those discussed in previous paragraphs of this section. Based on relatively few shots, these experiments indicate that the critical thickness of a steel barrier is of the order of one half of the critical air gap for lead azide donors and tetryl acceptors. Ratios for particular donor-accepter combinations varied between 0.375/1 and 0.70/1. Part of the variation in the ratios is apparently due to the existence of maxima in the metal barrier-density curves where none exist in the air gap density curves. The reasons for these maxima are discussed in the earlier section headed "Density effects."

In some larger scale tests, similar to those described in section 2 of chapter 7, various materials, including several waxes, several plastics, aluminum, copper, and wood were compared with air as barrier materials. In these tests, the critical thickness for most materials was about 0.4 times the air gap (with slightly lower values for copper and wood) when the acceptor charge was tetryl or pentolite. With less sensitive acceptors, such as cast Composition B, the critical air gap was much closer to the critical wax barrier thickness, and in some cases actually smaller. In these tests it was also found that, with some acceptor materials, the critical barrier thickness was increased by interposing an air gap between the barrier and the acceptor. It will be noted that in these tests the barrier is of the same diameter as the booster. There is room for doubt as to whether the same results would be obtained with a barrier of much larger area.

Shaped Charge Effects

Angularly converging shocks may combine, under some circumstances, to form a shock of higher intensity than any of the component shocks. A three-dimensional converging shock can be obtained from an explosive charge by forming a cavity in its output end. The localized augmentation of explosive damage obtained by this means is known as the Munroe effect, after an early experimenter in the field. The effect can be greatly augmented by lining the cavity with metal, which is formed into one or more "jets" having velocities of the same order of magnitude and even greater than the detonation velocity of the explosive. Because these jets are composed of solid fragments, they retain their velocities and hence their penetrating effects over long ranges.

This effect was used in a wide variety of munitions during World War II and was the subject of a considerable amount of research and development. Reference (6) is a broad resumé of the principles un-

covered in this work. The application of shaped charge principles to explosive trains is discussed in reference (7). The work described in reference (7) was experimental work aimed toward the development of specific designs rather than basic research aimed at uncovering fundamentals. Figure 8–17 is a diagram of the arrangement of the experiments. Table 8–3 gives some of the results of these experiments. These data may be useful in providing a departure point for a designer who wishes to apply the shaped charge effect to explosive trains.

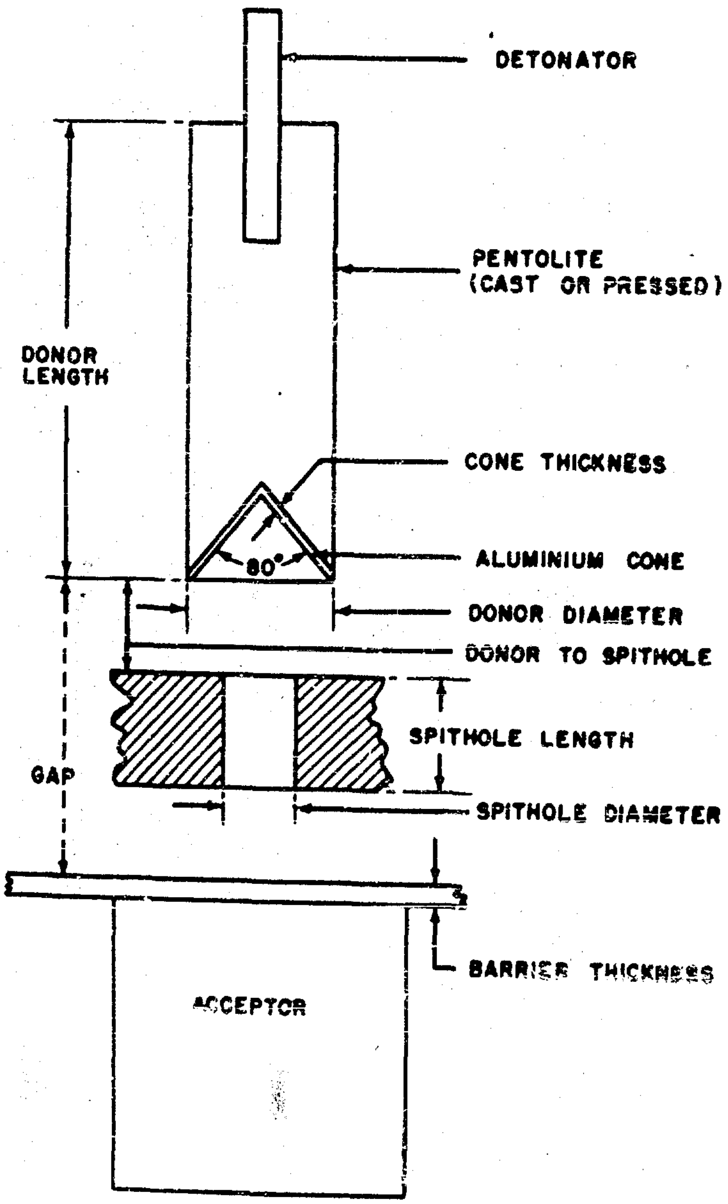


Figure 8–17. Diagram of Experiments on the Propagation of Detonation from Shaped Charge Initiators.

TABLE 8-3.—*A Compilation of Data From OSRD Report No. 5601 (ref. (7)) Showing Results of Tests of Shaped Charge Initiators as Illustrated in Figure 8-17 (All donors 50/50 Pentolite; all cones aluminum with 80 degree angles; all dimensions in inches; barriers steel and in contact with acceptor except as noted)*

Donor loading	Donor diameter	Donor length	Cone thickness	Donor to spit hole	Spit hole	Diameter length	Barrier thickness	Gap	Acceptor explosive	Acceptor fired/tried
Cast	0.375	1.0	0.012	4	0.375	1	0.010	7	Tetryl	27/29
Do	.375	1.0	.012	4	.375	1	.010	7	Pressed Pentolite	10/10
Do	.375	1.0	.012	4	.375	1	.010	7	Cast Pentolite	7/10
Pressed	.375	1.0	.012	4	.375	1	.010	7	Tetryl	7/8
Do	.375	0.75	.014	(1)	(1)	(1)	.010	7	do	1/5
Do	.375	0.75	.014	(1)	(1)	(1)	None	7	do	5/6
Do	.375	1.0	.014	(1)	(1)	(1)	.010	7	do	3/3
Do	.375	1.0	.014	0	.375	8	.010	8	do	10/10
Do	.375	1.1	.014	0	.375	8	.010	8	do	10/10
Do	.375	1.5	.014	0	.375	8	.010	8	do	8/10
Do	.375	1.0	.014	0	.375	15	.010	15	do	8/10
Do	.375	1.5	.014	0	.375	15	.010	15	do	10/10
Do	.50	2	(1)	(1)	(1)	(1)	.019	18	do	8/8
Do	.50	2	(1)	(1)	(1)	(1)	.019	20	do	1/1
Do	.50	2	(1)	(1)	(1)	(1)	.019	24	do	1/1
Cast	1.0	2.5	.038	24	2.0	23	[2] .027+.017	48	do	20/20
Do	1.0	2.5	.038	(1)	1.0	(1)	.027+.017	29	do	10/10

[1] Not given.
[2] A steel barrier (0.027 inch) was placed 1 inch from the donor and a brass barrier (0.017 inch) in contact with the acceptor.

Some experiments at the Naval Ordnance Laboratory indicate that substantial increases in critical gap can be obtained even with charges as small (about 0.150 inch diameter by 0.5 inch long) as the detonators usually used by the Navy.

Many commercial blasting caps have small "dimples" in their bases. Although these bases are not at all well proportioned as shaped charge liners (they are much too thick, for one thing), they do form into slugs which can substantially increase the initiating range of these caps particularly when the acceptor is relatively sensitive. This fact may, for example, account for the extreme range over which, one hears, dynamite is sometimes initiated by blasting caps (40 feet according to one account).

It has been found that, although the effectiveness of shaped charge ammunition is considerably reduced by the rotation of spin stabilized projectiles, the influence on the effectiveness of the small jets used in explosive trains is very small. The reduction in effectiveness due to rotation is a centrifugal effect related to the diameter.

In the application of the Munroe effect and related phenomena to explosive train designs, several points must be kept in mind. These effects do not in any way increase the energy available from an explosive charge. Their effect is that of concentration. Thus these effects depend for their usefulness on accurate alignment and symmetry of all components of the donor and of the donor with the acceptor and any small openings through which the donor must shoot. The shaped charge as used in explosive trains is primarily a device for transmitting detonation over relatively large distances. Its value in augmenting the reliability of initiation over short ranges has been questioned although it is believed that a properly designed shaped charge can improve reliability of propagation even between charges in direct contact.

An example of an application of the shaped charge in explosive trains is the Army's Point Initiating Fuze M90.

Section 4.—References

Parenthetical numbers preceded by the letter "S" are Naval Ordnance Laboratory file numbers.

(1) NOLM 10926, **Redesign of Underwater Detonators—Development Work.** May 22, 1950.

(2) NOLM 10065, **Optimum Blow-Through Hole Diameter for Mk 113 Primers.** March 18, 1949.

(3) NAVORD Report No. 70–46, **The Stability of Detonation.** June 1946. (S–10775).

(4) Ordnance Board Proceeding No. 30870 with Enclosure dated April 15, 1945. (British) (S–6300).

(5) NOLM 9707, **The Effect of Air Gaps on the Initiation of a Lead by a Detonator.** June 25, 1948.

(6) Journal of Applied Physics, Vol. 19, No. 6, pp. 563–582, June 1948, **Explosives with Lined Cavities.**

(7) OSRD Report No. 5601, **Point Initiating Fuzes for Shaped Charge Weapons.** January 3, 1946. (S–8205).

Chapter 9

MEASUREMENT TECHNIQUES

The measurement of fuze explosive component performance consists mainly of a determination of (*a*) the input characteristics, and (*b*) the output characteristic.

Many of the instruments and techniques available for making these determinations are of recent development, having been produced under a program set up in early 1947 to provide more adequate means for controlling fuze and fuze component quality and performance (ref. (1)).

In general, "input characteristics" may be considered synonymous with sensitivity. Sensitivity measurements are usually concerned with the energy required to insure initiation of the explosive component. This initiating energy may be supplied in mechanical, electrical, or thermal form, and must be measured without undue disturbance of the firing system or appreciable energy consumption by the measuring device.

"Output characteristics" embrace all the physical phenomena which may result from an explosion. Since an explosion may deliver heat, light, and sound as well as mechanical energy in the form of high-pressure waves, high-velocity gases, and high-velocity particles, the particular aspect of the energy output that must be measured often depends greatly on the application of the component. Thus in a detonator application, it may be most important to determine the intensity of the shock wave delivered to the succeeding lead or booster; while in certain primers, the ability to drive a small piston may be the primary consideration.

A few miscellaneous tests that fall under neither input nor output characteristics may be noted. Surveillance tests may be resolved into a succession of input and output measurements in which the variation of these measurements with time in storage is of interest. Measurements of the delay times of pyrotechnic delay components, of the effectiveness of sealing and moisture proofing, and of mechanical ruggedness under impact conditions are among these miscellaneous test procedures. These tests will be referred to briefly at appropriate points.

For purposes of ready reference, the principal output and input test sets in use by the Navy are listed in table 9–1, together with an indication of the field of usefulness of each.

TABLE 9–1.—*Standard Test Sets for Firing Train Components*

Mk	Mod	Type of apparatus	Nature of test	Component tested	Range of charge	Remarks
135	0	Drop Ball Tester	Sensitivity in terms of drop height.	Percussion Primers Mk 101, Mk 105, etc.	Under 100 mg. of primer charge.	Standard steel sphere drops on blunt firing pin.
136	0	do	Sensitivity in terms of drop height. Output in terms of lead disk perforation.	Stab primers and stab detonators.	Up to about 100 mg.	Standard steel sphere drops on sharp pointed firing pin.
146	0	Sand Bomb Apparatus 60 gram.	Output in terms of weight of standard sand crushed.	Electric primers and electric detonators.	100 mg. to 600 mg	Maximum of 30 grams of sand to be crushed.
147	0	do	do	Percussion detonator such as Detonator Mk 1.	do	Essentially the same as Mk 146 Mod 0 but provided with firing pin.
148	0	Sand Bomb Apparatus 200 gram.	do	Electric primers and electric detonators.	100 mg. to 1.2 grams	Maximum of [illegible] grams sand to be crushed.
149	0	do	do	Percussion detonators similar to Detonator Mk 1.	do	do.
150	0	Sand Bomb Apparatus 3[illegible]0 gram.	do	Electric Torpedo Detonator Mk 9.	Up to 3.[illegible] grams	
151	0	do	do	Percussion Torpedo Detonators Mk 7 and Mk 8.	do	
52	0	Sand Bomb Apparatus 500 gram.	do	Electric detonators such as Mk 46 Mod 0.	To about 200 mg	Maximum of [illegible] grams of sand to be crushed.
58	0	Condenser Discharge Apparatus.	Sensitivity in terms of electrical energy in condenser discharge.	Electric primers such as Mk 114.	About 120 mg	Discharge known condenser at known voltage into primer bridge wire.
72	0	Torsional Ballistic Pendulum.	Output in terms of momentum given pendulum.	Electric Primer Mk 114.	Up to about 150 mg	Primer mounts in pendulum bob and jet of gases delivers impulse to pendulum system.
72	1	Torsional Ballistic Pendulum.	do	Percussion Primers Mk 101, Mk 105, Stab Primers Mk 102, Electric Primers Mk 114.	do	Similar to Mod 0 but pendulum bob is arranged to fire percussion and stab primers.
173	0	Drop Ball Test Set Mk 135 plus chronograph and thermocouple	Sensitivity in terms of drop height and firing delay; output in terms of thermocouple emf.	Percussion Primers Mk 101 and Mk 105	Up to about 50 mg	Firing delay is measured for each sample fired. Delay from impact to issue of flame is a measure of sensitivity. Thermocouple reads temperature-time integral.

173	1	Drop Ball Test Set Mk 138 plus chronograph.	Sensitivity in terms of drop height and delay.	Stab primers and stab detonators such as Mk 102 and Mk 33.	Up to about 200 mg. .	This device awaiting further development.
174	0	Gas Explosion Chamber	Sensitivity in terms of initial pressure of H_2-O_2 gas mixture which fires 50% of sample.	Flash detonators such as Mk 29, Mk 33, Mk 45, and Mk 54.	Up to about 250 mg. .	Run with Bruceton schedule, using initial gas pressure as the independent variable. The detonation of the gas fires the detonator.
175	0	Gas Volume and Impulse Apparatus.	Output in terms of maximum and steady displacement of mercury column.	Percussion and stab primers such as Mk 101, and Mk 102.	Up to about 60 mg. . .	Primer fires above mercury reservoir, driving a column of mercury up a capillary tube.
176	0	Sand Bomb Apparatus 500 gram.	Output in terms of weight of standard sand crushed.	Percussion Detonator Mk 53 Mod 0.	Up to 1.5 grams.	
180	0	Pressure Bomb Apparatus.	Output in terms of pressure developed in known volume.	Electric primers such as Mk 114.	Up to about 150 mg. .	Obtain oscillographic record of pressure vs time as primer fires.
214	0	Hopkinson Bar Apparatus.	Output in terms of peak pressure of a compression wave in a steel bar.	Flash, electric and stab detonators.	Up to about 300 mg. .	

In the discussion that follows, the field of measurement techniques has been divided into sensitivity and output measurements. Each of these divisions is concerned with two types of initiators: (*a*) components such as detonators and leads that initiate booster type explosives; and (*b*) components such as primers that initiate primary explosives, black powder or pyrotechnics, or that do mechanical work.

Section 1.—Sensitivity Measurements

Any useful measurement of explosive component sensitivity must involve a direct or indirect measurement of the initiating energy delivered to the sample. Energy must always be delivered to the sample at a finite rate. If this rate of energy delivery is known, it is frequently possible to evaluate the "threshold" or minimum firing energy in terms of the rate of energy delivery multiplied by the time of application up to the instant of firing. In some cases the rate of energy delivery is too rapid for such a simple procedure to be applicable. This is usually the case, for example, in condenser discharge firing of electric primers. The rate of energy application is also a factor in determining the sensitivity in some instances. This is particularly noticeable when very slow rates of energy application are involved. In this connection, see page 3-36, Effect of Rate of Energy Input in Bridge-Wire Type Primer.

Initiators of Booster-type Explosives (Detonators)

Stab detonators. Stab initiated detonators are usually tested in some form of drop weight apparatus. Test Set Mk 136 (ref. (11)) is typical of such devices; it is illustrated in figure 9-1. In Test Set Mk 136, the initiating energy is supplied by the impact of a freely falling steel sphere upon a firing pin which rests lightly against the sample. The total energy of the steel sphere at contact is simply the weight of the sphere times the height from which it has fallen.

By considering the construction of the apparatus more closely, it can be seen from figure 9-1 that the test sample is mounted in a plastic holder on top of a precisely located anvil. A heavy shield surrounds the anvil and sample holder. A small opening in the upper surface of the shield is accurately aligned with the plastic holder so that the firing pin may be inserted in the tubular part of the holder above the test sample after the shield has been closed. The upper end of the firing pin protrudes slightly above the shield. The steel drop ball is held by an electromagnet that may be raised or lowered by a jack screw. Accurate alignment of the drop ball with the axis

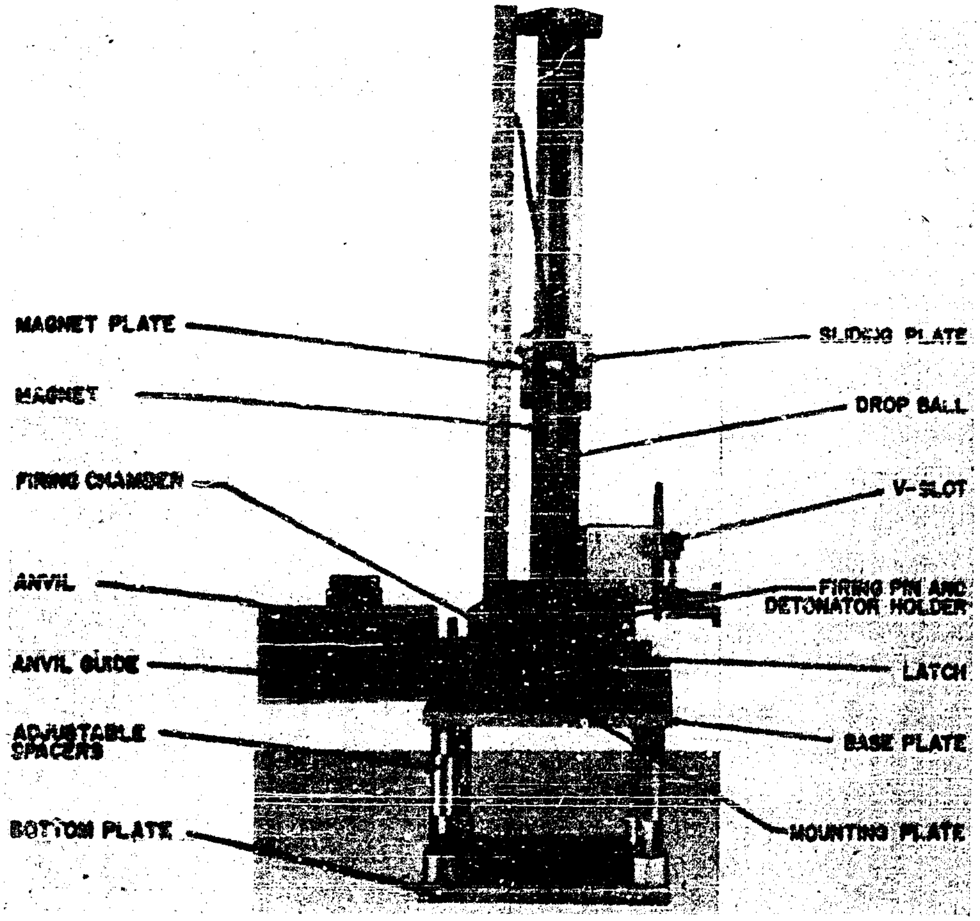


Figure 9–1. Test Set Mk 136 Mod 0 for Stab Primers and Stab Detonators.

of the firing pin is secured by a concave magnet pole piece. Tolerances are closely held on the firing pin contours as well as on the drop ball weight in order to insure reproducible test results. The firing pin and plastic holder are expended when the sample fires.

The test procedure employed in the operation of Test Set Mk 136 may assume either of two forms. Firing may follow the "Bruceton" or "staircase" method in which the drop height is increased one unit following a misfire and decreased one unit following a fire, or it may follow the "Frankford" or "rundown" method in which the percentage firing at each of a series of drop heights is obtained. Some further discussion of these methods is included later in this section under General Remarks on Sensitivity Tests, page 928. In the Bruceton test the results are reported in terms of the height $\overline{X}$ at which 50 percent of the samples will fire. In the Frankford test, the data may be reported for any chosen percentage of firing.

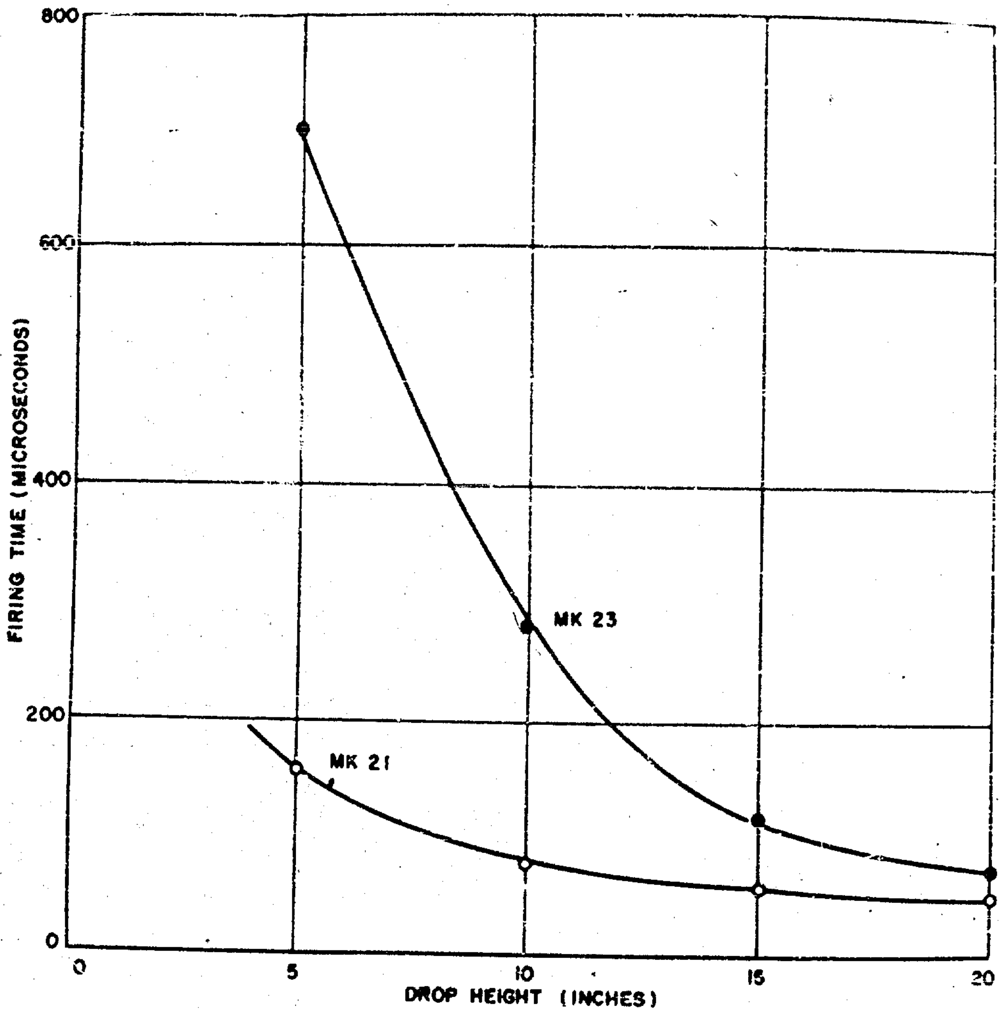


Figure 9–2. Firing Time vs. Drop Height for Stab Detonators.

It will be noted that the initiation energy is applied at a moderate rate in Test Set Mk 136 since the drop ball never attains a velocity in excess of about 135 inches per second, and usually has velocities from 30 to 60 inches per second. This being the case, a measurement of the time interval between drop ball impact and the first evidence of explosion should permit some estimate of the actual initiation energy required by the test sample, or at least give an indication of the margin by which the sample fired for a given drop ball energy. The measured time will be that between the drop ball impact and the later instant when the cup has been sufficiently indented or perforated to cause initiation. This time for indentation or perforation depends upon the drop ball velocity at impact as well as on the depth of indentation required. For a particular cup design, the required indentation will vary inversely as the sensitivity of the explosive.

It would therefore be expected that shorter firing times would be measured as the height of fall increased. That this is the case is shown in figure 9–2. This measurement is most conveniently accomplished by a modification of Test Set Mk 173 which is described later in this section beginning on page 9–23.

Electric detonators. The sensitivity of electric detonators may be determined by either of the two methods mentioned in section 3 of chapter 3, under Effect of Rate of Energy Input in Bridge-Wire Primer (page 3–36). These two methods may be termed (*a*) the "condenser discharge" method and (*b*) the "constant current" method. With either method, the operating procedure may follow the Bruceton or the Frankford firing schedule to obtain the desired information. With both methods the aim is to measure the electrical energy input necessary to bring the ignition bridge up to the initiation temperature of the explosive. Since a bridge wire of given dimensions and material must reach a definite temperature in order to initiate the explosive in which it is imbedded, it is evident that the rate of energy input is an important consideration. Thus a bridge wire may reach thermal equilibrium with its environment at a temperature well below the initiation temperature if the rate of energy input is low, and therefore a large total energy may be delivered without initiation.

In the condenser discharge method, the rate of energy input is usually high. This is accomplished by making the RC discharge time short compared with the cooling time of the bridge. The short duration of the RC discharge time often introduces difficulties in the design of test instrumentation as is discussed later.

A satisfactory apparatus has been assembled (ref. (2)) and has been used to obtain most of the data of section 3 in chapter 3. This test apparatus has been designed to handle a wide variety of electric detonators and electric primer sensitivity tests, and is rather too elaborate for designation as a standard test set. The condenser discharge apparatus includes a precision condenser decade box, a regulated voltage supply capable of precise voltage adjustment (ref. (2)), a compact firing chamber with an ingenious safety interlock system that prevents accidental firing with the door open, and a mercury contact relay to connect the charged condenser to the electric detonator terminals. A more detailed description of these components follows.

The precision condenser decade enables a rapid choice of any capacity value up to 1.110 microfarads in steps of 0.001 microfarad. These condensers are of the best available quality, thus minimizing errors due to dielectric absorption and dielectric leakage. Loss of charge due to leakage and incomplete discharge due to dielectric

absorption must be avoided in order that the input energy may be accurately computed.

The regulated voltage supply permits a rapid adjustment of the charging voltage with a precision of ½ percent from about 1 volt up to 150 volts. This corresponds to a precision of 1 percent in the stored energy, which is expressed by the equation $E = \frac{1}{2}CV^2$.

The firing chamber is a cubicle of armor plate fitted with a sliding door for access. Connection to the detonator is made by short leads through the chamber wall to the interlock switch. At the switch terminals, very short leads run to the mercury relay and condenser decade.

The firing relay is a heavy duty Mack mercury relay which is suitable for high current surges. This item is perhaps the most critical in the whole assembly, for switching losses may introduce very serious errors in the test results if not detected. Many varieties of switches and relays have been tested for this application, but none have been completely satisfactory. The Mack relay is the best of those tested with regard to reproducibility and freedom from erratic contact resistance, particularly when used at potentials below about 60 volts. While the actual energy transfer efficiency of the Mack relay is not precisely known, it has been found that the energy transferred is a linear function of the applied energy and that the transmitted energy curve extrapolated goes through the origin when transmitted energy is plotted against applied energy. Thus there is no constant energy loss, and whatever losses may exist are a fixed and reproducible proportion of the applied energy. No contact chatter occurs with the mercury relay.

In using the condenser discharge apparatus, the chosen condenser is charged to the desired voltage, quickly disconnected from the charging source, and connected to the Mack relay, which is then energized to complete the circuit to the detonator. This whole operation is accomplished in a small fraction of a second to insure no loss of charge from the condenser.

When detonators with low resistance bridge wires are tested on this apparatus, the RC discharge times are very short. For example, when a 1-ohm bridge wire is used, the maximum time constant at the start of the discharge amounts to about 1 microsecond, since only about 1 microfarad of capacity or less is usually required. In many cases the time constant is of the order of $\frac{1}{10}$ microsecond. Since such short duration pulses are being transmitted, it is essential that the wiring from the condenser through the relay and interlock switch to the detonator be as short as possible to minimize stray inductance and capacitance effects. It is considered that stray inductance in particu-

lar will result in an oscillatory discharge which is prone to disturb the test results.

The firing procedure on a condenser discharge sensitivity test may involve selecting a particular capacity and varying the charging voltage to obtain different discharge energies. Alternatively, it is possible to select a particular charging voltage and to vary the condenser capacity to obtain the desired energy levels. In this latter case, the RC discharge time varies from energy level to energy level, but this may cause no difficulty if the variations are small, and the longest time constant is still short compared with the bridge wire cooling rate.

No standardized test set is available for constant current firing of electric detonators; although, as in the case of condenser discharge testing, constant current firing apparatus has been designed and in use for some time. The design of a suitable constant-current firing system is a more involved problem than is condenser-discharge design, and so far has been handled on a piecemeal basis with no attempt being made to construct a universal test set. The reason for this procedure lies in the wide range of currents to be delivered and the equally wide range of bridge resistances into which the current must be delivered.

Two alternative approaches are available. One is to choose a "ballast resistance" that is many times higher in resistance than the bridge of the detonator to be tested, taking into consideration any changes in bridge resistance during firing. When the bridge resistance and the ballast resistance are connected in series across an adjustable constant voltage source, the ballast resistance is most effective in controlling the current which flows. For example, if it is desired to supply 1 ampere to a bridge wire which has a cold resistance of 2 ohms and which may reach 6 ohms when hot, the ballast resistance might be chosen as 100 ohms. Then the applied voltage would be adjusted to 102 volts, thus causing 1 ampere to flow in the total resistance of 100+2 or 102 ohms. When the bridge wire reached a resistance of 6 ohms, the current would drop to $\frac{102}{106}$ or 0.962 amperes. Thus the current is maintained constant to within 4 percent despite a three-fold increase in the bridge wire resistance. It should be noted that the ballast resistor must be rated at 100 watts or more for this application, and that the ballast resistor rating becomes almost prohibitive when higher currents are desired unless the tolerance on current regulation is relaxed. Thus, to supply 5 amperes to the same bridge wire at 4 percent regulation would require the 100 ohm ballast resistor to have a rating of 2500 watts, and the voltage

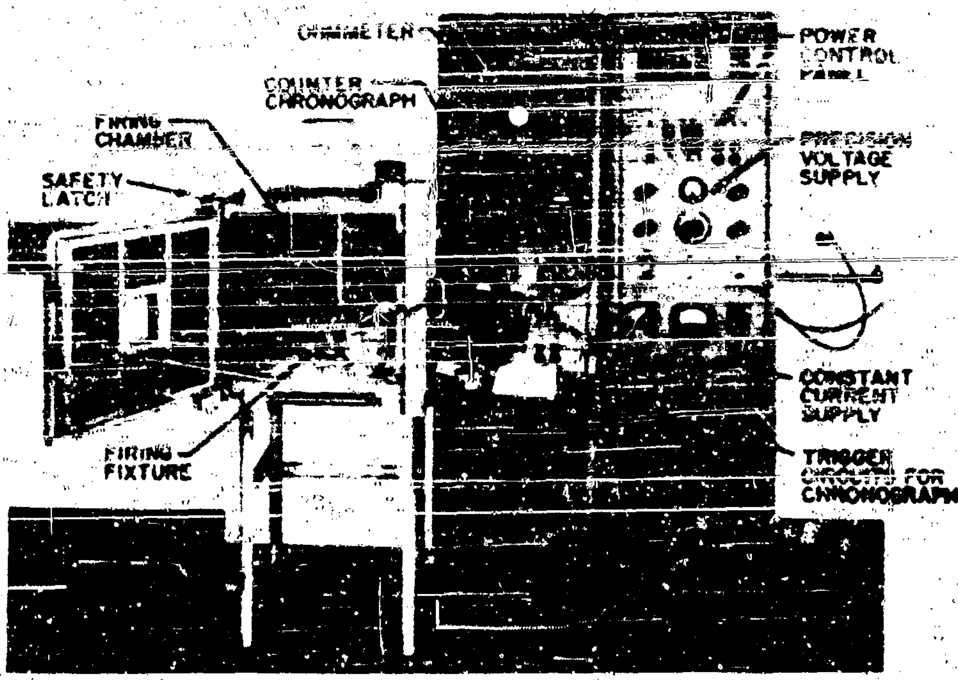


Figure 9–3. Electric Primer and Detonator Test Equipment.

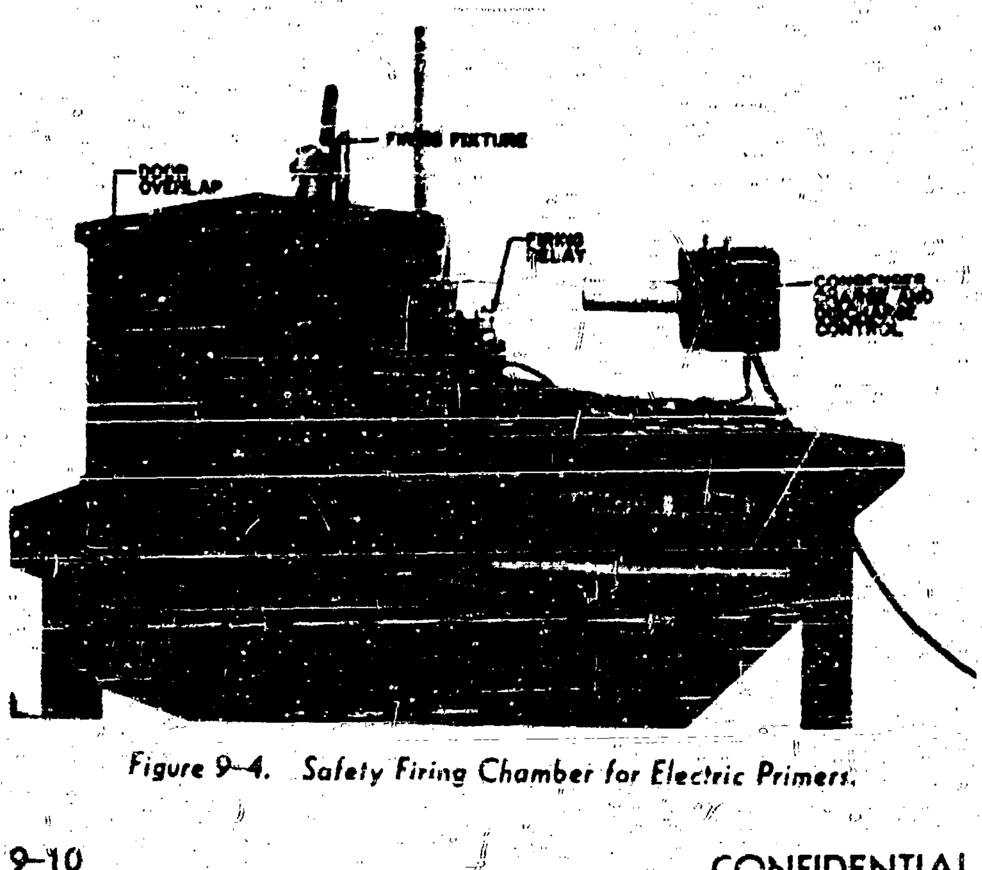


Figure 9–4. Safety Firing Chamber for Electric Primers.

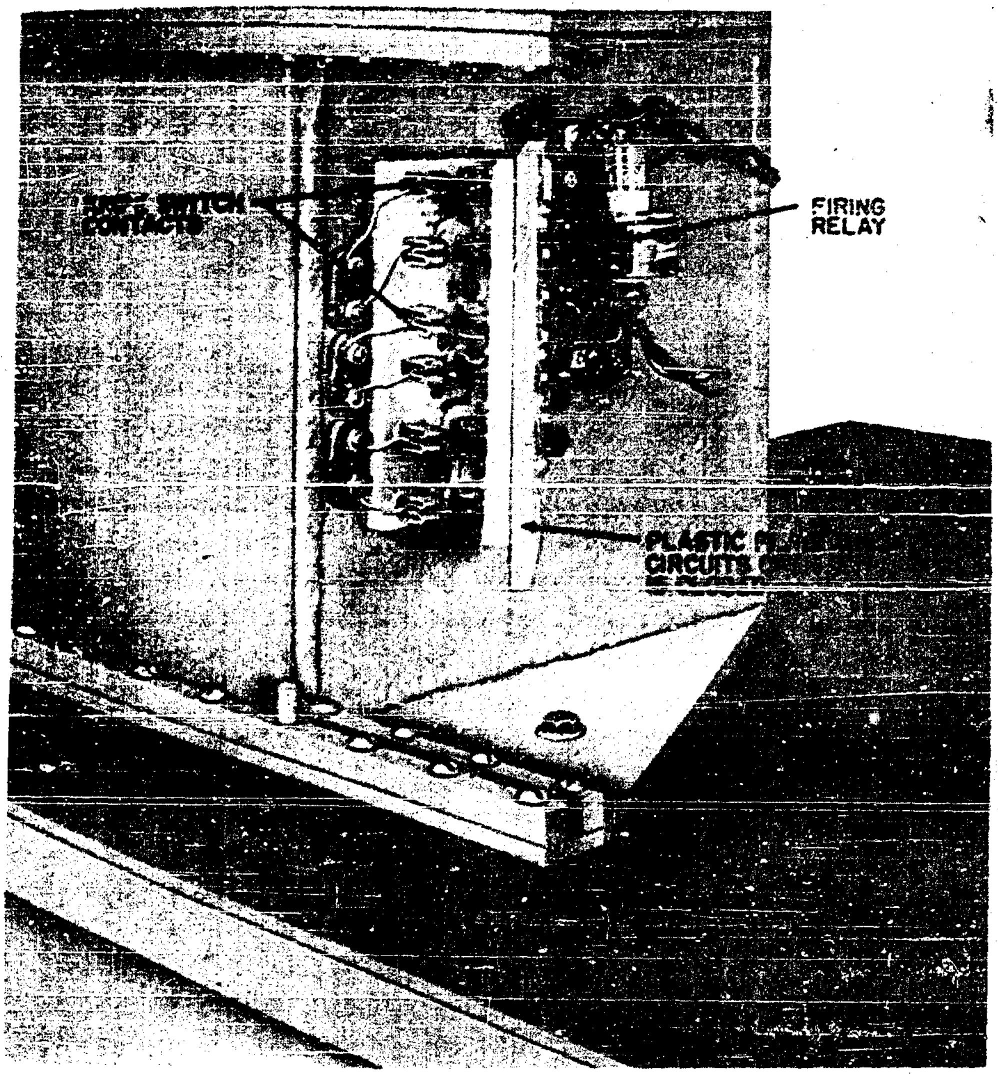


Figure 9–5. Detail of Interlock Switch for Safety Firing Chamber.

source would have to be capable of delivering 510 volts at 5 amperes. In general, however, the bridge wires which require large currents are those which have rather low resistances, so that equivalent current regulation may be achieved with lower ballast resistances and lower supply voltages.

In actual practice, of course, the supply voltage is maintained at 250 volts, which is commonly available, and the ballast resistance is adjusted to the value appropriate to the desired current, this adjustment being made with a dummy resistor in place of the bridge wire. Effectively this results in better than average current regulation for small firing currents and poorer current regulation for large currents. Some equipment of this nature is shown in figures 9–3, 9–4, and 9–5.

The second alternative involves the use of constant current vacuum tubes to regulate the current. Power pentodes such as the 6L6 or 807 may be used in parallel to reach the desired current rating, or even larger transmitter type pentodes may be utilized. Actually, in principle, the constant current pentode circuit is not essentially different from the ballast resistor scheme but offers the convenience of using the vacuum tube as a self-adjusting ballast resistor. Relatively little work has been done with this type of constant current supply for electric detonator firing except in the very low current range.

In both the ballast resistor and the vacuum tube circuits, it has been necessary to establish the desired constant current through a short circuiting switch across the terminals of the detonator bridge and then to transfer the current to the bridge by opening the switch. This procedure avoids difficulties with switching transients in the main power source and appears to be satisfactory as long as the bridge resistance is very much higher than the shorting switch contact resistance. Where the bridge wire resistance is not high relative to the switch contacts, the switch must be connected across a series combination of the bridge wire plus a resistance which is high relative to the switch contacts yet low relative to the ballast resistor. To use the previous example of a 2-ohm bridge, the shorting switch should show a resistance not much over 0.02 ohm if it is to be used safely. If a switch having 0.05-ohm contact resistance were used it would be advisable, when working at the higher firing currents, to connect a 3-ohm resistance in series with the detonator and to connect the switch across the detonator-resistor combination. This added resistance would have no serious effect on the constant-current characteristics of the system.

It has been mentioned that the constant-current firing procedure may utilize either the Bruceton or the Frankford schedules. It is also possible, with constant-current firing, to improve the quality of the data by making a simultaneous measurement of the time of current application up to the instant of firing. In general, for two detonators of equal bridge resistance, the detonator sensitivity will be inversely related to the firing time at a given current. In this connection, see the references under electric primers, later in this section (page 9–27).

Flash detonators. The sensitivity of flash initiated detonators may be measured by the application of a controlled pulse of thermal and mechanical energy to the sensitive end of the detonator. Because of inherent engineering difficulties in the production of such controlled pulses, sensitivity tests for flash initiated components have been much slower in development than have tests for other components.

Since a flash detonator is usually initiated by a burst of flame and hot particles from an exploding primer or pyrotechnic delay, one of the obvious approaches to the problem of sensitivity testing is that of using primers as the initiating agency. This technique has often been applied in the past for lack of anything better and has sometimes given apparently satisfactory results for a particular set of conditions. It is occasionally used when a new type of detonator is to be substituted for a former variety using the same initiating primer.

This technique has several serious defects. In the first place, the normal spread in the output intensity of fuze primers is fairly great, so the applied energy can only be very roughly controlled. In the second place, the best way to obtain a controlled variation in the applied energy is to use special primers with weight-graduated loads covering the range of primer output desired. If any pretence of accuracy is to be maintained, samples of the weight-graduated primers should be tested for output energy versus charge weight on equipment such as Test Set Mk 173 discussed on page 9–46.

In most cases the output of a primer varies directly as the charge weight, but this should be verified experimentally in each case. Figure 9–6 shows some firing data collected in this manner. Reference (9) includes some sparse data on the initiation of flash detonators by weight graduated Primers Mk 101. While the tests were actually conducted as output tests on Primers Mk 101, they may equally well be considered as input or sensitivity tests for fuze Detonator Mk 28. For example (See table VII of reference (9)), the shellac-sealed primers at 3 mg charge produced only 40 percent functioning, but primers with charges of 6 mg and over produced 100 percent high order detonation. The sample sizes used were entirely inadequate for any valid computation of the sensitivity of Detonator Mk 28, but the tests do indicate that the use of graduated primers is a feasible method of flash detonator sensitivity testing when more elaborate instrumentation is not at hand.

Another approach to flash detonator sensitivity measurements has been found in various high-temperature submersion tests. In such tests, a bath of molten Wood's metal or solder is maintained at a constant temperature and the sample detonator is suddenly submerged in the bath. The time to detonation is measured as an inverse function of sensitivity. In general, these tests are more relevant to "cook-off" than to flash sensitivity, for the time lags are of the order of seconds. See references (3) and (4) regarding such tests.

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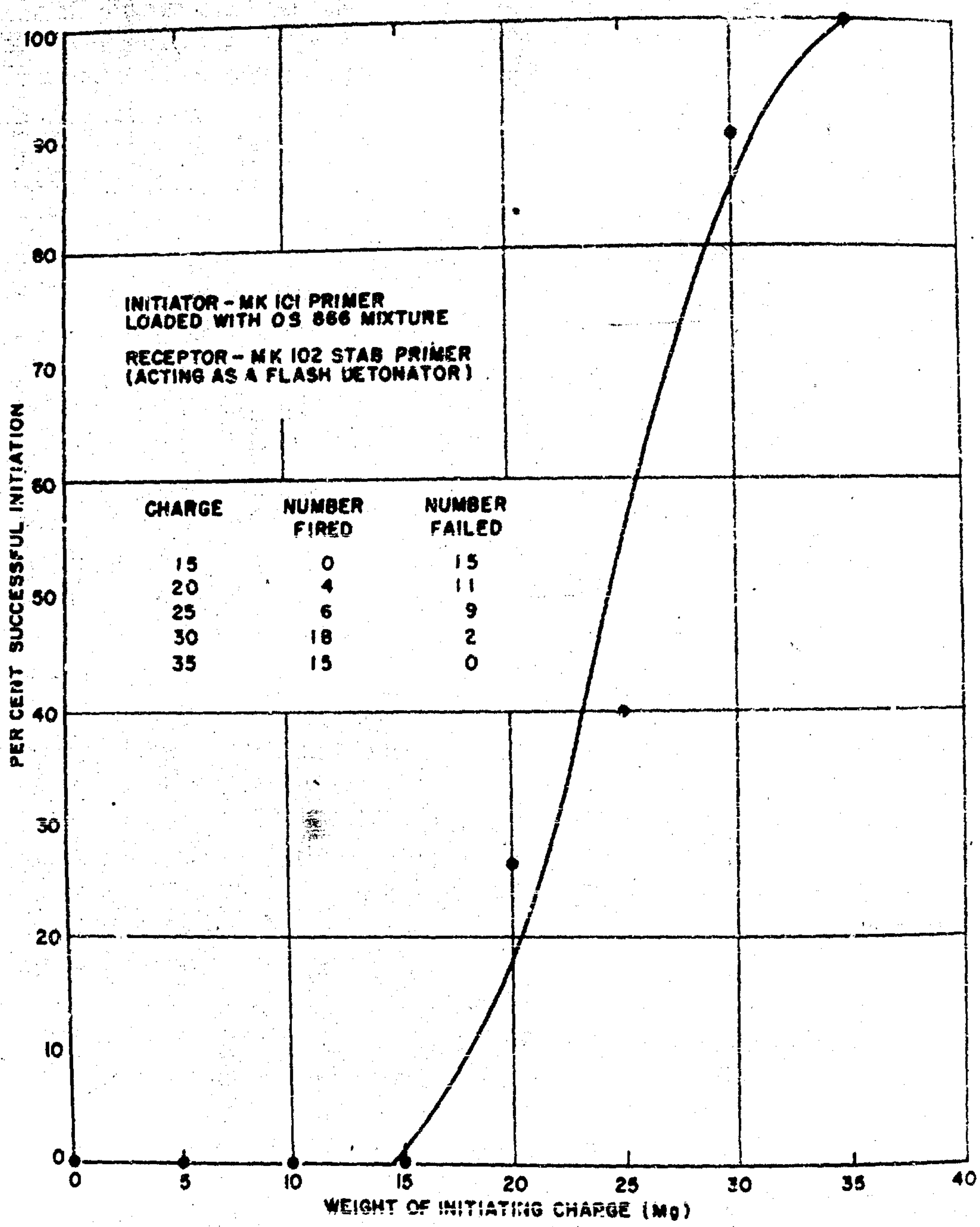

Figure 9–6. Initiation of Flash Sensitive Charges by Varying Primer Loads.

Related closely to the molten bath tests are those that involve the application of blow torch flames of various intensities to the sensitive ends of the detonator samples. Some data on blow torch tests are given in references (3) and (5). Blow torch tests were reported upon favorably in the latter reference, with rather short initiation times indicated; but the results of subsequent tests have failed to reproduce the original short time lags. The work of reference (5) was done with an unusually intense flame from an underwater cutting torch burning

hydrogen with oxygen within a sheath of excess air formed by compressed air jets, and it is possible that the conditions were not reproduced in the later tests.

While it is of some theoretical interest to determine whether or not the tests of reference (5) can be reproduced, the practical aspects of the torch tests are not so attractive. Very serious difficulties are encountered in obtaining reproducible flames because of severe damage to the torch tip by particles from the detonator. No adequate shutter mechanism is available to trip at the start of detonation and to shield the torch tip from the detonation before damage can be done.

Additional information relevant to the initiation of detonators in molten metal baths is given in reference (6). Ubbelohde, on the basis of tests with various primary explosives loaded in No. 8 blasting cap aluminum cups, set up equations for the ignition delay at any temperature in the form:

$\log_{10} t = \frac{E}{4.57T} + B$ where t=ignition delay, seconds;

E=activation energy, kilocalories/mole; and T=temperature, degrees C.

In arriving at this equation, it was assumed that the time required for heat transfer from the bath to the explosive was negligibly small. By measuring the molten metal bath temperature, which resulted in a 5-second ignition delay, he was able to evaluate the constants in the equation for each of several explosives. Using the resulting equations, he predicted both the temperatures necessary for initiation in times of the order of 1 millisecond, as well as for 10 microsecond delay times. For mercury fulminate, for example, initiation occurred in 5 seconds with a 208° C bath; bath temperatures of 437° C and 683° C were predicted for 1 millisecond and 10 microsecond ignition times. The corresponding temperatures for lead azide were 343° C, 551° C, and 735° C, respectively. These predicted temperatures appear to be in the range that should be readily attainable with blow torch flames, hence flame initiation should be possible with ignition times of a few milliseconds. The discrepancy between these predictions and the measured time delays with conventional torch flames has yet to be fully explained, but it is probably due to the lower heat content of the low pressure flames.

The one apparently successful approach to flash sensitivity measurements has been achieved with Test Set Mk 174 Mod 0. An early version of this equipment is described in reference (5), and the present

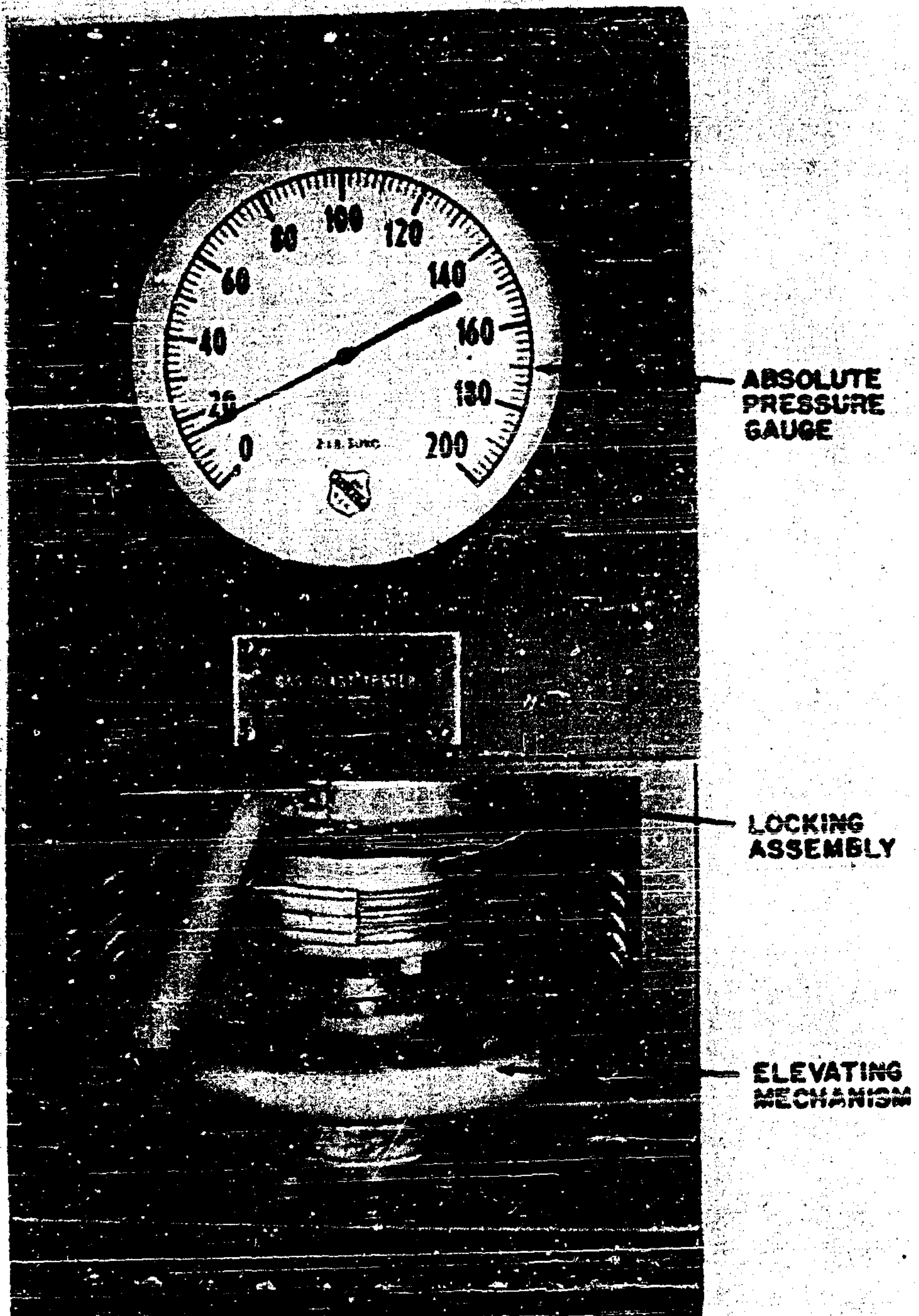

Figure 9–7. Flash Detonator Tester, Front View. Test Set Mk 174 Mod 0.

form of the equipment is covered in reference (7). This apparatus (fig. 9–7) consists of a heavy firing chamber into which the sample detonator may be sealed along with a charge of stoichiometric H_2–O_2 gas mixture at a known initial pressure. The explosive gas mixture is ignited by a spark plug; if the initial pressure is high enough, successful detonation of the sample is obtained. By varying the initial gas pressure over a range of values, it is found that initiation of the samples

may be varied from 0 percent to 100 percent along a fairly smooth curve. This ignition of the detonator by the gas explosion occurs so rapidly that the sound of the exploding detonator cannot be distinguished from the sound of the gas explosion. No reliable measurements of the actual time lag have been made to date.

Test Set Mk 174 Mod 0 (fig. 9–8) has provided much interesting data on flash detonator sensitivity. One group of tests on Detonator Mk 29 demonstrated the pronounced effects of lacquer coatings on the flash sensitive end (ref. (8)), as well as the extent of deterioration between 5-year-old samples as compared with freshly prepared units. This information is shown in figure 9–9. The reproducibility of data obtained on this apparatus appears to be satisfactory, and its ability to detect changes in detonator sensitivity appears to be excellent. As originally constructed (ref. (7)), it involved some safety hazards, due to hangfires. This difficulty has now been eliminated by the substitution of plastic detonator holders for the original copper holders, which reached and held a high temperature long after the gas explosion. Designs for an improved test set are being prepared.

Initiators of Primary Explosives and Pyrotechnics (Primers)

Stab primers. Sensitivity tests for stab initiated primers are accomplished in a fashion identical with that described earlier in this section under Stab detonators. Test Set Mk 136 is a typical example of test apparatus for this purpose. As in the stab detonator tests, either the Bruceton or Frankford procedures may be employed. Also as in the case of stab detonators, it is found that Test Set Mk 173 Mod 0 may be adapted to the timing of the firing pin penetration delay, and the resulting time delay data may be used as additional sensitivity criteria. The modification required in Test Set Mk 173 consists of a change in the dimensions of the "capacity cup" (described under Percussion primers, page 9–21) to suit the smaller drop ball generally used with Test Set Mk 136. A further change is called for in the design of the "ionization-capacity" stop probe assembly to suit the different arrangement of parts in Test Set Mk 136 as compared with Test Set Mk 135. Some typical test data on stab-primer delay times are plotted in figure 9–10. No extensive investigation of this technique has been undertaken so far for stab primers, nor have thermocouple measurements been employed.

A British report (ref. (10)) deals with efforts to minimize the penetration delay time in order to study the times involved in transmitting the explosion along the length of the primer and across gaps. The apparatus reported is claimed to reduce the time delay to a few microseconds or less.

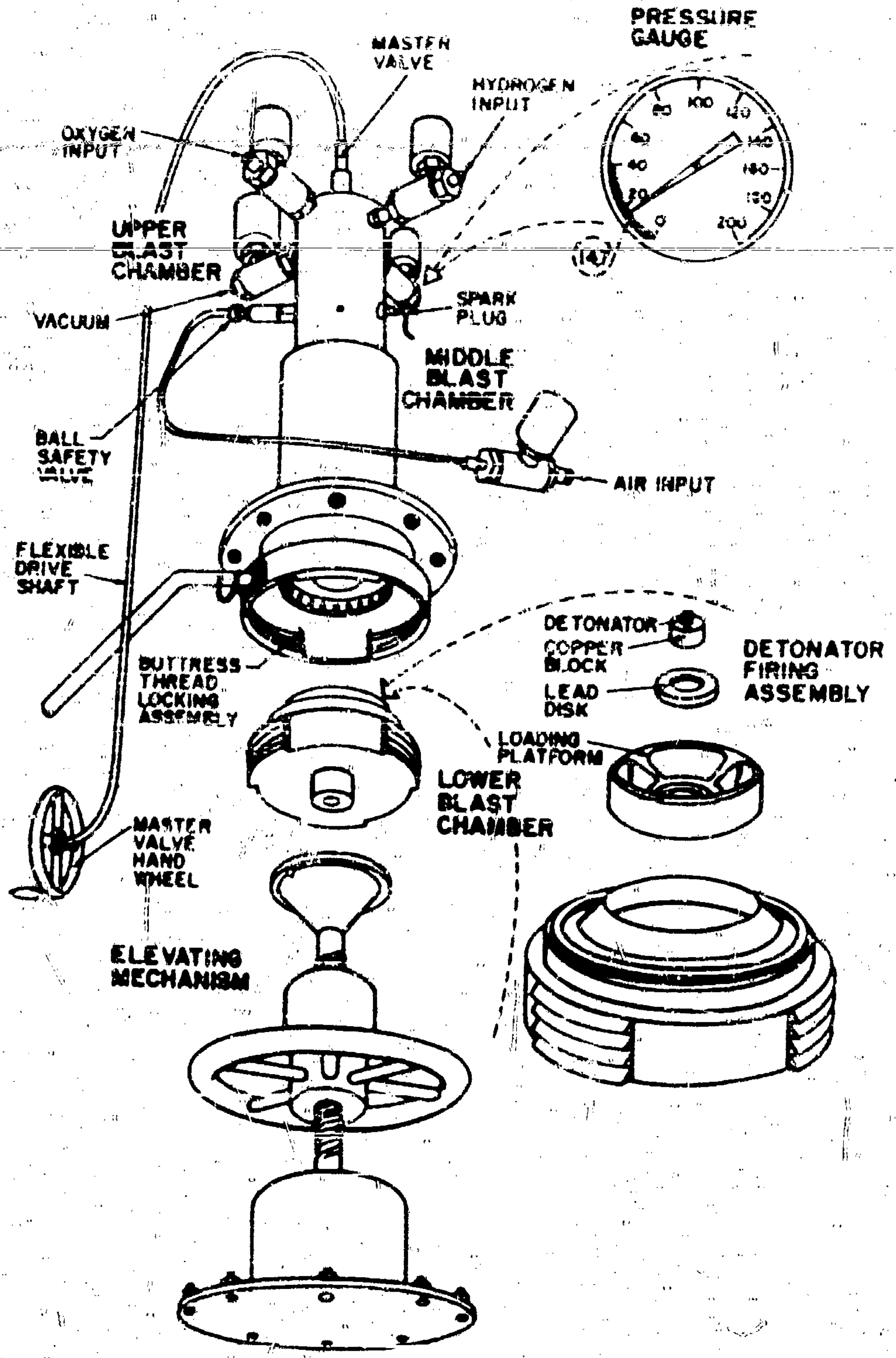

Figure 9-8. Oxy-Hydrogen Flash Detonator Tester Mk 174 Mod 0.

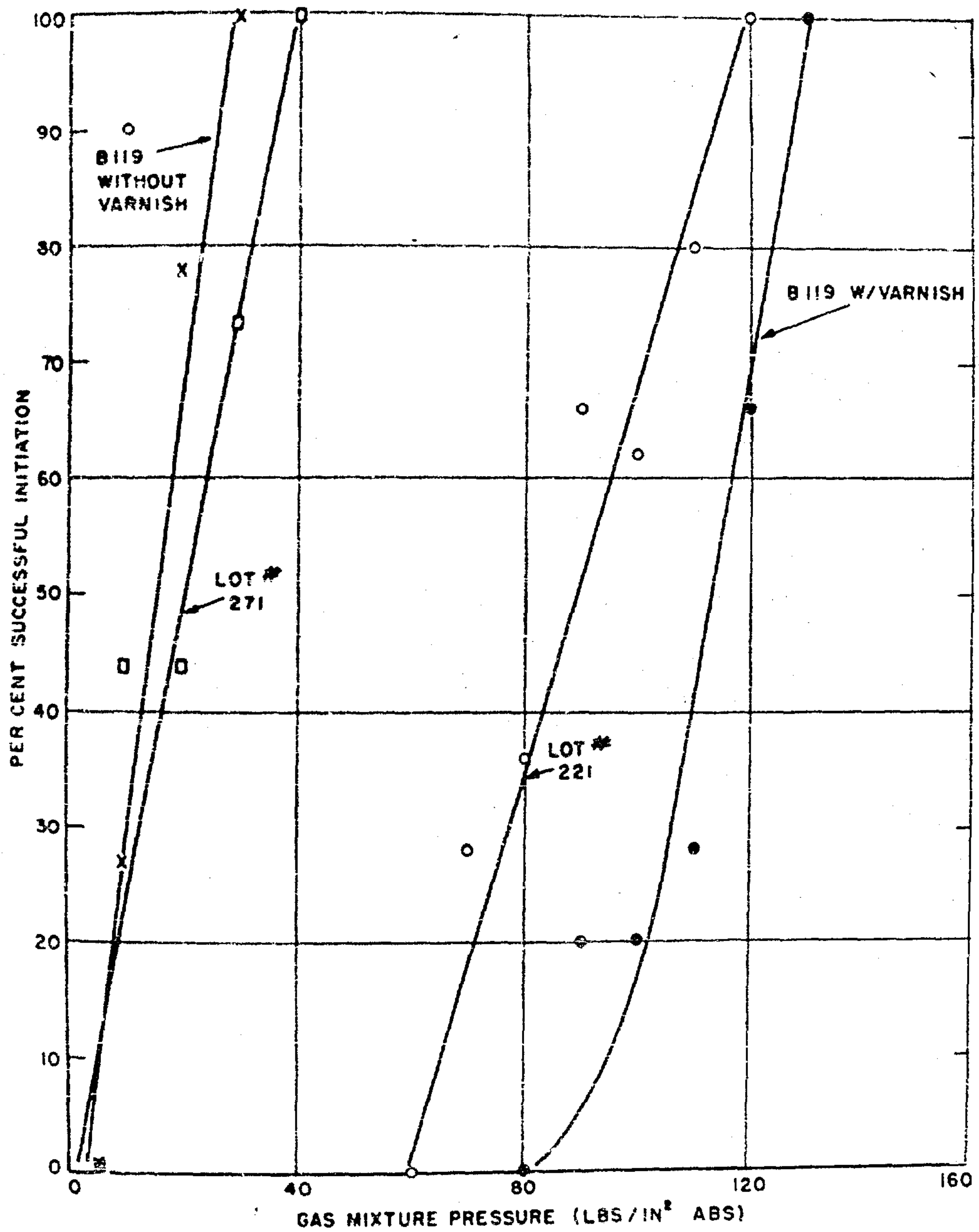

Figure 9-9. Sensitivity Tests of Detonator Mk 29.

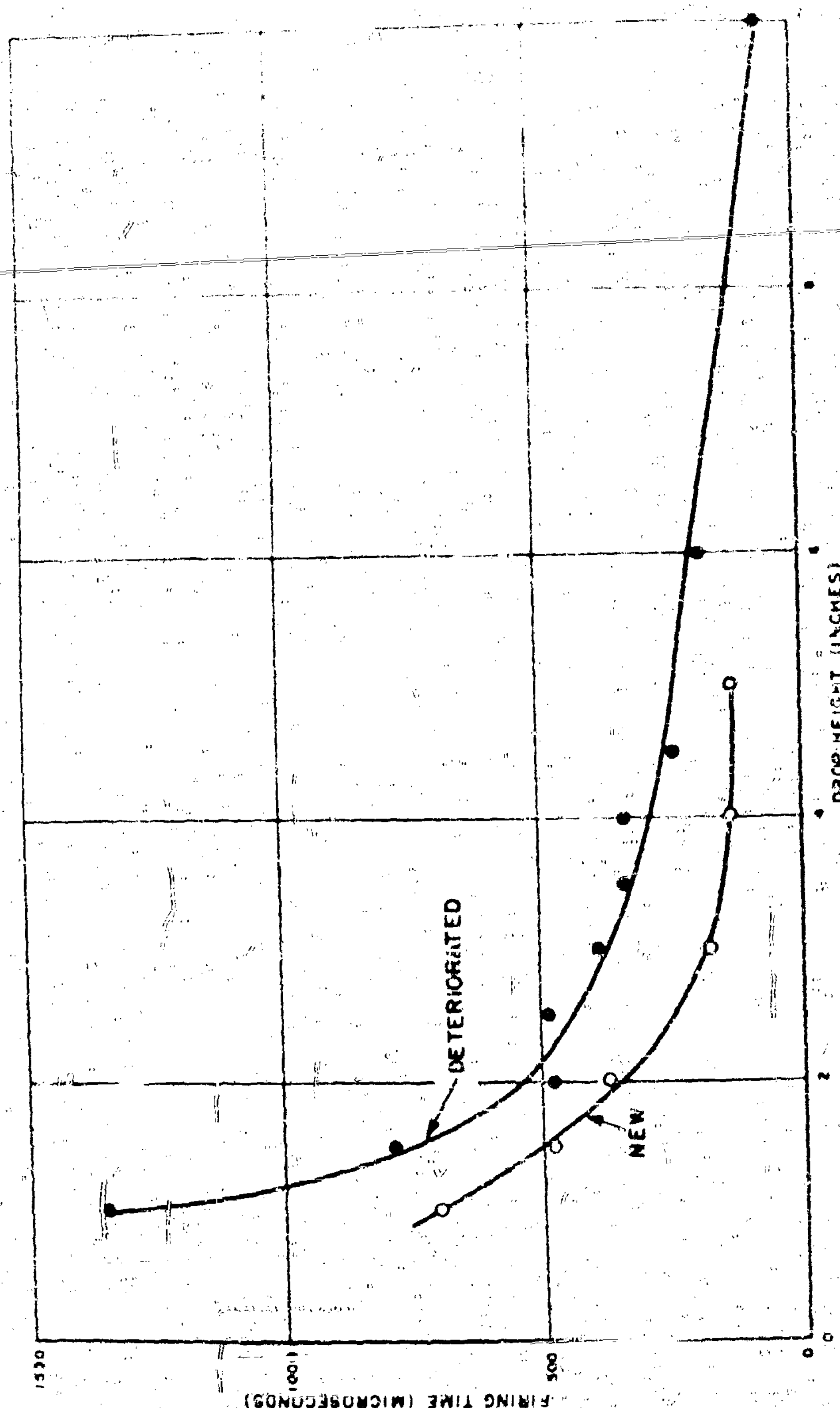

Figure 9-10. Firing Time vs. Drop Height, Stab Primers Mk 102.

Some experimental work has been done on stab primers in which the firing pin is made an integral part of the drop ball or plummet instead of having the firing pin initially at rest in contact with the stab primer. The results of these tests are reported in reference (66). This mode of operation differs but little from the more usual drop-ball method, and is seldom used because of the greater difficulty in obtaining a central impact on the primer. One point of difference does exist, however, and should be mentioned briefly here. When the firing pin and drop ball are an integral assembly, the kinetic energy of such a plummet should always be fully available for the initiation of the primer. This is not necessarily the case when a separate drop ball falls on a stationary firing pin.

For example, we may consider a 20-gram firing pin at rest on top of the primer. To a first approximation, if a 20-gram drop ball impinges upon this firing pin the drop ball would be brought to rest momentarily and the firing pin would start to penetrate the primer with an initial velocity equal to the impact velocity of the drop ball. The drop ball probably does not make contact with the firing pin again until after the explosion. If, on the other hand, the drop ball has a mass of 10 grams and strikes a 20-gram firing pin, it might be expected to rebound, retaining about 10 percent of its kinetic energy while 90 percent is delivered to the firing pin. A similar mismatch appears possible when the drop ball is more massive than the firing pin. The available experimental data (ref. (66)) are inconclusive, but if this effect can be shown to exist, it will be necessary to apply corrections to values obtained in drop ball measurements whenever a change in the ratio of ball to firing pin mass is made.

Percussion primers. Sensitivity tests for percussion-initiated fuze primers are usually performed upon some form of drop ball or drop weight apparatus. A fairly well developed form of this equipment is exemplified by Test Set Mk 135 for percussion primers. Figure 9–11 shows the principal features of this test set, and reference (12) comprises the list of drawings for this test set. As in the case of Test Set Mk 136, there has been no report published specifically pertaining to the apparatus, but NAVORD OD 5823 describes the installation and operation of the test set.

Figure 9–11 shows that Test Set Mk 135 is essentially similar to Test Set Mk 136 previously described, except for the lower structure which houses the sample. In Test Set Mk 135, the sample primers are mounted in individual holders which are inserted into appropriate recesses in a six-position turntable. The turntable is so designed that each of the six indexed positions brings a primer (in its holder) directly below the standard firing pin. When everything is in readiness for

firing, the firing pin is lowered into contact with the center of the primer cup and the drop ball released by disconnecting power from the release magnet. The height from the top of the firing pin to the lower surface of the drop ball may be adjusted by a jackscrew arrangement as is done with Test Set Mk 136. Special precautions are taken in setting up the equipment to assure that the drop ball drops squarely on the axis of the firing pin, and that the firing pin rests accurately at the center of the primer cup. The release magnet is provided with a concave pole piece to locate the drop accurately over the firing pin center.

Test Set Mk 135 has been operated until recently on either the Bruceton or the Frankford firing schedules, which are discussed later in this section under General Remarks on Sensitivity Tests (page 9–28.)

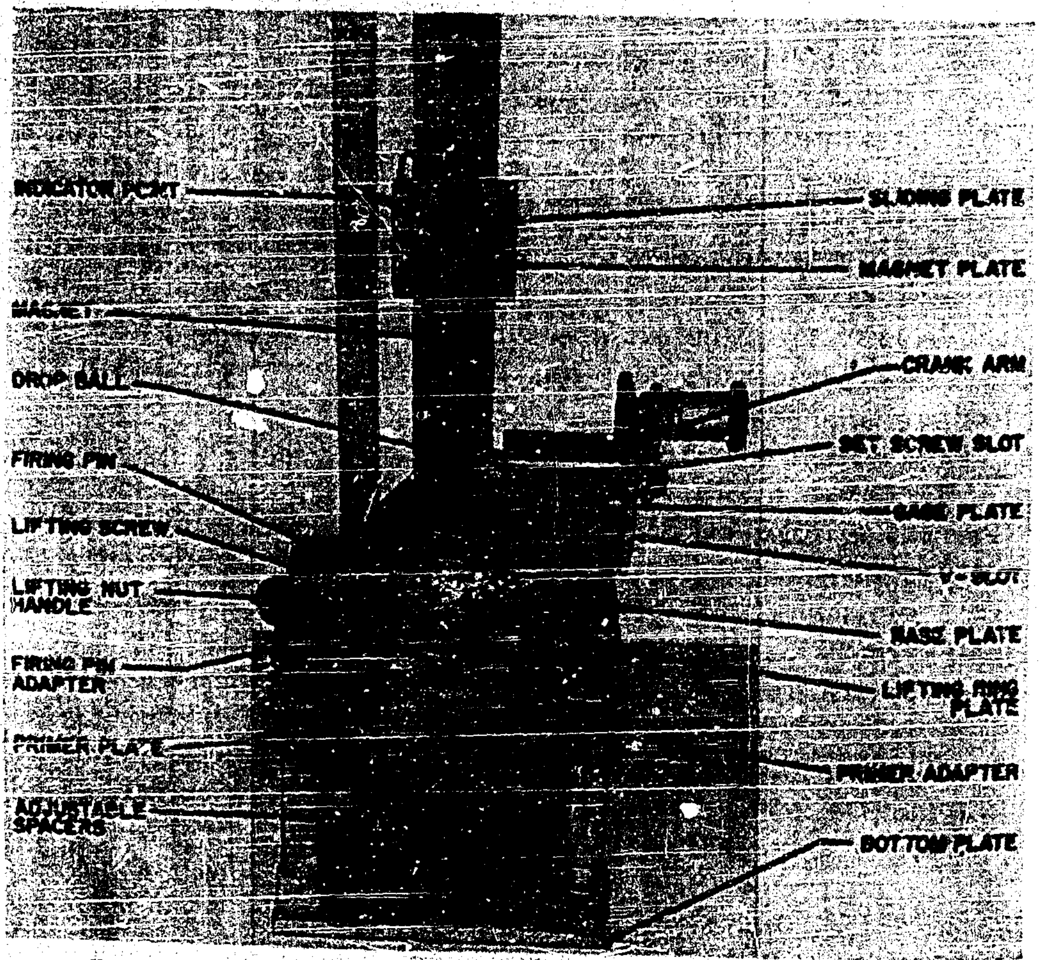

Figure 9–11. Test Set Mk 135 Mod 0 for Percussion Primers.

The data are most commonly reported in terms of the 50 percent firing point, $\bar{X}$, and the factor σ, which is a measure of the scatter in the data. Many of the data in the section on percussion primers have been recorded in this fashion.

More recently, the completion of Test Set Mk 173 Mod 0 has made possible the collection of a greater amount of information per sample expended than was the case in the earlier sequential or staircase tests. Test Set Mk 173 utilizes the mechanical structure of Test Set Mk 135 but also includes an electronic chronograph and appropriate fittings to permit measurement of firing delay times. Additional features of Test Set Mk 173 for comparative heat output measurement are described on pages 9–46 and 9–47. Information regarding the electronic circuits of Test Set Mk 173 is given in reference (13). Earlier phases of the development of Test Set Mk 173 are described in references (14), (15), (16), (17), (18), and (19). A photograph of the completed test set is included as figure 9–12, while a block diagram of the timing equipment is presented in figure 9–13.

The principles underlying the operation of Test Set Mk 173 Mod 0 are simple and straightforward. An electronic timer or chronograph is started at the instant the drop ball strikes the firing pin and is stopped when flame issues from the primer. The time interval so measured is made up of three portions, namely (*a*) the penetration time of the firing pin from drop ball impact to mixture initiation, (*b*) the time from mixture initiation to first emission of reaction products, and (*c*) the flame transit time from primer to pickup device. The sum of intervals (*a*) and (*b*) is the important variable for the purposes of this test, whereas the flame transit time is approximately constant for a given type of primer and explosive.

To a fairly good first approximation, the energy delivered to the explosive mixture in a particular type of primer must be proportional to the depth of indentation produced by the firing pin as a result of the drop ball impact. The time required to initiate the primer, that is, the time required to produce sufficient indentation to deliver threshold firing energy to the explosive mixture, will thus be a function of the impact velocity of the drop ball and, therefore, will be long when the drop ball is released from a small height, and short when the drop ball release height is great.

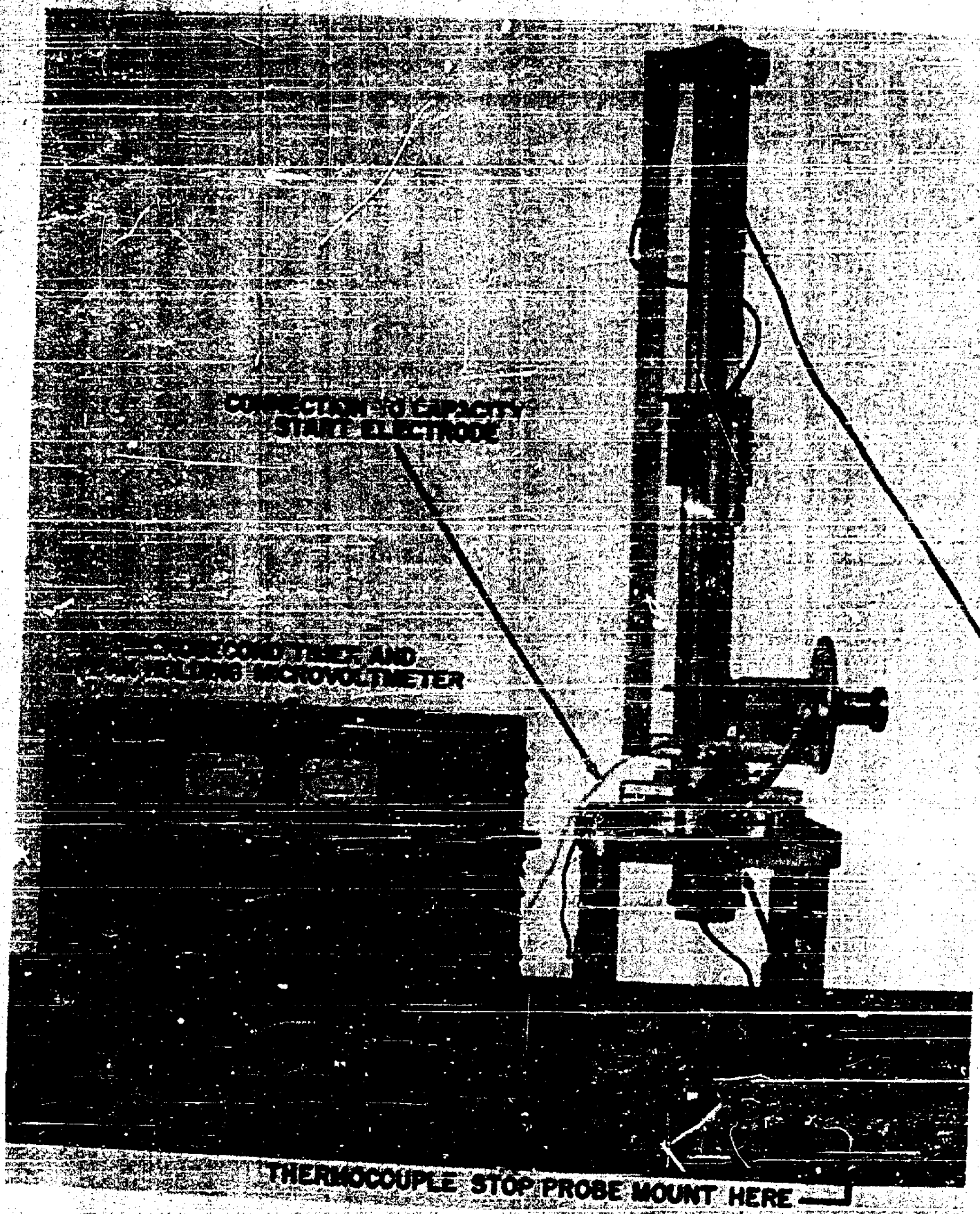

Figure 9–12. Test Set Mk 173 Mod 0 for Percussion Primers.

On the other hand, for a given drop ball impact velocity, the firing time will vary inversely as the primer sensitivity, since the more sensitive the primer mixture, the smaller the indentation required for firing. Thus, if firing times are measured at a given drop height on successive samples of primers during surveillance, it is found that as the primer sensitivity deteriorates, longer and longer initiation delay times are recorded. Such a test could be conducted at the all-fire point of the deteriorated primers, thus obtaining sensitivity data

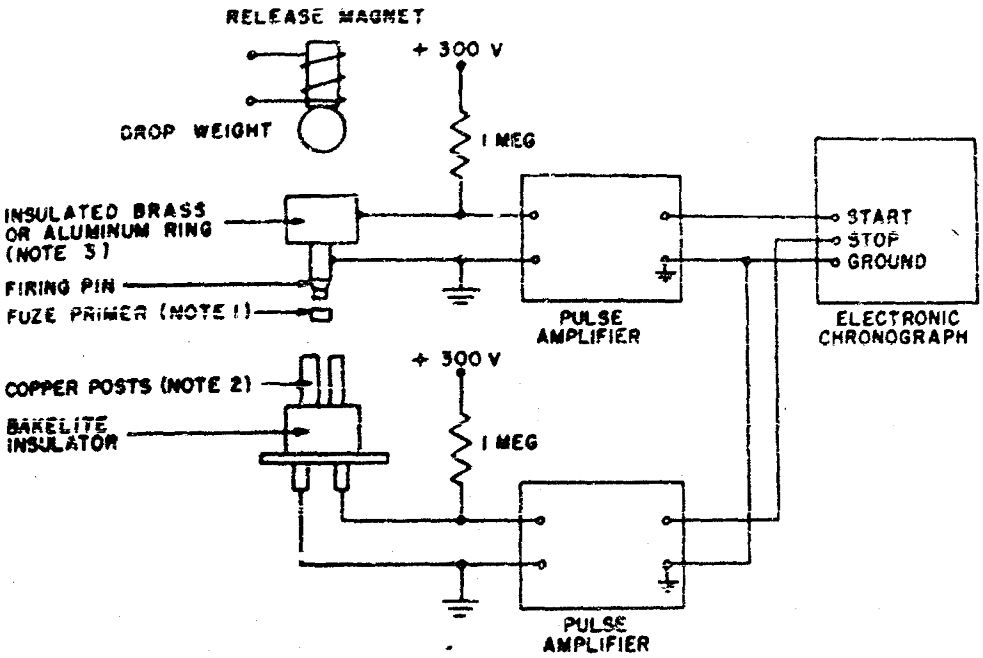

Figure 9–13. Block Diagram of Timing Equipment.

Note 1. The fuze primer is held rigidly in a fixture which also serves to guide and position the firing pin and to locate the "capacity-ionization" probes relative to the primer.

Note 2. The "capacity-ionization" probes function in a dual fashion. For explosives providing no ions, the change in dielectric constant due to the presence of reaction products causes a transient change of capacity. When ions are delivered, the ion current delivers a transient pulse.

Note 3. The insulated metal ring delivers a pulse when the drop weight discharges its induced charge to the firing pin.

Note 4. The pulse amplifiers and chronograph shown separately in this diagram are combined with other electronic equipment in a single unit as shown at the left in figure 9–12.

without any need for misfiring half of the sample group, as must be done in the "staircase" sensitivity tests. Some typical firing time curves are shown in figure 9–14 as an indication of the performance of Test Set Mk 173 when used with percussion primers.

The circuit details of Test Set Mk 173 are well described in references (13) and (14) and need only brief mention here. The instant of drop ball impact is determined by an ingenious capacity-change circuit which is simple and rugged and which absorbs no energy from the drop ball. The contact of the drop ball with the grounded firing pin causes an abrupt change in the capacitance to ground of an insulated cup surrounding the upper end of the firing pin. This capacity change is translated into a sharply rising voltage pulse which is amplified and utilized to start the electronic timer. An inexpensive

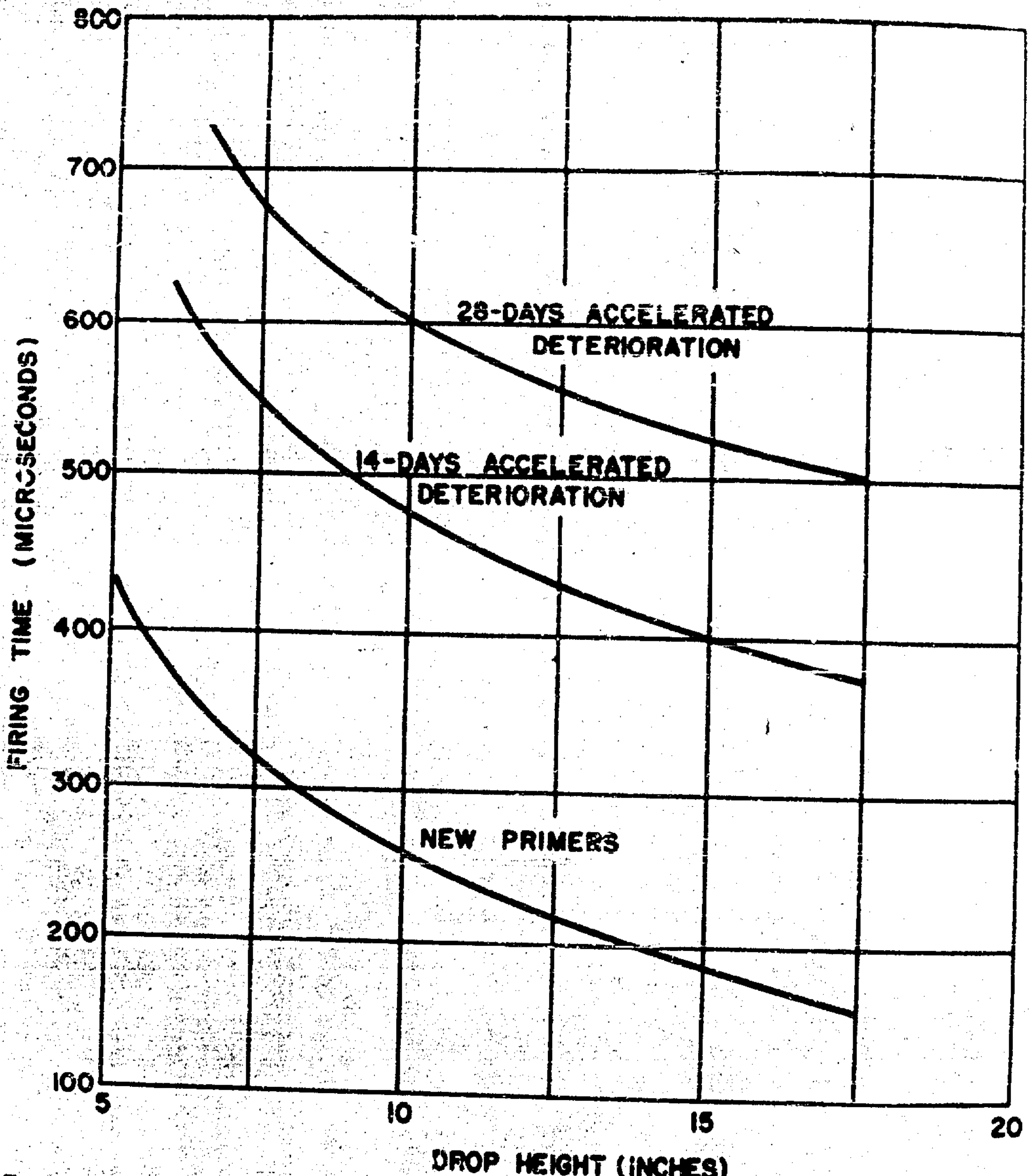

Figure 9–14. Typical E‸perimental Results, Firing Time vs. Drop Height of 4-Ounce Sphere. Typical Fuze Primer, Mercury Fulminate Mixture.

but reliable condenser-type electronic timer is incorporated in the test set, but other timers such as the counter type could be employed quite readily. The timer is stopped by a sharply rising pulse which is delivered when the ionized flame or gases allow conduction between two insulated electrodes adjacent to the primer. In some cases the flame is very sparsely ionized, and it is necessary to rely on a slight change in the capacity between the electrodes which occurs when the hot gases form the dielectric. Operation of the electronic equipment and associated pulse generating circuits has proved to be simple and their performance has been reliable to date.

Another device for the investigation of percussion primer sensitivity is the Piezo-Electric Impulse Gage, described in reference (20). This apparatus permits a laboratory study of the instantaneous firing pin force as a function of time. The variation in firing pin force from impact to explosion is displayed on the screen of a cathode ray oscillograph, and may be photographed if desired. The measurement of firing pin force is accomplished by the use of a composite firing pin-drop weight assembly which includes a piezo-electric crystal (quartz or tourmaline) so placed that it responds to the force acting on the firing pin. The measurement of force as a function of time does not fully specify the energy input to the primer, but only the impulse or momentum delivered; consequently, the device by itself does not provide a complete sensitivity test. Equipment to provide not only a force-time curve but a simultaneous displacement-time curve is currently being considered, but it is expected that wire strain gage techniques will be substituted for the piezo-electric method described in reference (20).

Electric primers. Sensitivity tests for electric primers are conducted in the same fashion as sensitivity tests for electric detonators, and essentially the same apparatus is employed. See an earlier topic in this section entitled Electric detonators. Firing may be by condenser discharge, constant current, or constant voltage methods, using "staircase" or "rundown" test schedules. "Square pulse" modifications of the constant current and constant voltage methods have also been applied in some test programs; in these methods instead of abruptly applying a steady current or voltage and maintaining it until firing occurs or until some long period has passed (20–30 seconds), the current is abruptly applied and maintained at a constant value for a definite short interval and then removed. The duration of application may be adjusted from a few milliseconds to some hundreds of milliseconds by suitable circuit design.

It has been found possible in some electric primer type components to measure the firing delay time under constant current conditions as an additional source of sensitivity data. The multipurpose test apparatus described earlier in this section under Electric detonators includes facilities for measuring this initiation delay time when desired. It also might be mentioned at this point that Test Set Mk 173 Mod 0 also embodies suitable electronic circuits for this measurement, although an auxiliary firing energy source would have to be provided. The use of adjustable length constant current pulses is an alternative method for obtaining approximate initiation delay times. Considerable test work of this general nature has been reported. See references (21), (22), (23), (24), and (25) in this connection. Refer-

ence (26) describes an electronic counter type chronograph which might serve for such measurements of initiation delay time, although the timers of references (17) and (18) are less expensive and entirely adequate for the purpose.

Where more elaborate measurements of electric primer sensitivity are desired, it is feasible to measure simultaneously the current through the primer and the applied voltage across the primer terminals, both as a function of time up to initiation. This calls for oscillographic recording techniques and is a rather laborious process, but it should permit an accurate estimate of the energy threshold of each primer tested. The change in bridge wire resistance during the period of current flow necessitates the dual measurement of current and voltage if good results are to be obtained, although it is sometimes possible to judge from the slope of a single curve the extent of the resistance change. See reference (27) in this connection.

The piece of equipment known as Test Set Mk 152 Mod 0 has been standardized for sensitivity testing of electric primers such as the Mk 114. This equipment (ref. (28)) provides a simple production test and involves the use of a standard capacity in a condenser discharge circuit of known constants.

General Remarks on Sensitivity Tests

Sensitivity tests are usually performed for one or more of the following purposes: (*a*) to determine the energy the preceding firing train component must deliver to insure that the train does not fail, (*b*) to measure the extent of variations in manufacture for quality control and specification purposes, and (*c*) to measure the deterioration resulting from storage under various conditions. In a critical firing train design, it would be necessary to consider both (*a*) and (*c*) to assure proper functioning after storage.

In the measurement of sensitivity, it is desired that the tests afford the maximum certainty for the fewest samples expended, regardless of the purpose of the test (although the test purpose may determine the maximum sample size which may be economically used). A considerable amount of statistical investigation has been devoted to the problem of test procedures for economical sensitivity testing. The design of experimental procedures has been covered in references (29), (30), (31), (32), (33), (34), (35), (36), and (37).

The main limitation in explosive component testing has been the fact that only one trial may be made upon each sample. A misfired

sample is generally sufficiently damaged to render a second test unreliable, and, of course, a fired sample is completely destroyed. This situation differs from that in many other fields of study. For example, if it is desired to measure the heights or weights of all the school children in a given district, it is possible with ruler or tape or scales to obtain a height or weight figure for each individual child and then to tabulate the number (or percent of the total number) having heights in each of a series of different height ranges. Such measurements lend themselves to rather simple and straightforward statistical analysis. On the other hand, in the case of explosive components it is difficult to determine directly the threshold firing energy of each sample as one would the height of each school child. In the drop weight test apparatus or the condenser discharge equipment, each trial involves delivering a known amount of energy to the sample. If the sample fails, the older drop test methods afford no clue as to whether the sample failed by a large or a small margin, and, similarly, when a sample fires there is no clue as to whether the sample just barely fired or whether it might have fired with half the energy applied. This would correspond, in the foregoing example, to choosing a height before seeing the individual child and then recording only whether the child was taller or shorter than the preselected height. The statistical problem is that of pre-selecting the heights according to the best schedule so that the taller-shorter judgments have the most significance.

One of the more widely used approaches to this problem is the "staircase" method. In the Bruceton test, which is typical of the staircase method, the severity of each successive test is determined by the success or failure of the preceding test. In starting the test, an effort is made to make the first drop somewhere in the vicinity of the expected 50 percent firing height. If a failure occurs on the first drop, the next sample is tested at one unit greater height and if the first drop is a fire, the second sample is tested one unit lower. The test continues in this fashion, height increasing after a failure and decreasing after a fire, until all the samples have been tested. The usual minimum number of samples is 50. The increment of height designated as one unit is usually ½ inch or 1 inch, depending upon the expected standard deviation (σ) of the lot, it being desired to fire in steps of about ½ to 1 times σ. Calculation of the 50 percent height is then performed according to a simple routine.

Reference (29) describes some seven varieties of staircase test procedures, including the Bruceton, and rates these tests according to various considerations. The Bruceton test affords a fairly good estimate of the 10 percent, 50 percent and 90 percent firing points

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for minimum trials, but depends heavily on the assumption that the sample sensitivity follows a normal distribution about the median firing height. Alternate tests are listed which are less dependent on normal distribution. None of these tests, however, will reveal the presence of complete duds.

Reference (30) extends the analysis of staircase methods to samples having other than normal distribution. Reference (31) describes the precise procedures involved in Bruceton tests, with sample data sheets and typical calculations for the 50 percent point, σ, 10 percent point and 90 percent point.

Where large samples are available, the Frankford "rundown" procedure affords perhaps the simplest method of all. This requires that a fixed number of trials be made at each of a succession of drop heights which span the range from no-fire to all-fire. The percentage firing at each height may then be plotted as a function of height, and the height for any desired percentage of firing may then be obtained by interpolation. Some preliminary information as to the approximate no-fire and all-fire heights is necessary in order to properly space the various height levels, but this may be readily obtained from a Bruceton run or from prior experience. Reference (37) describes the Frankford procedure in detail and indicates the appropriate methods for interpreting the test data. In general, a satisfactory Frankford run-down requires 25 to 50 samples at each of at least 5 heights, or a minimum of about 125 to 250 samples in all.

In both the Bruceton and the Frankford tests, it is usual to report $\overline{X}$, the median or 50 percent firing height, and σ, the standard deviation. In the Frankford acceptance tests, acceptance has been based on a sliding scale for $\overline{X}$ wherein a wider range of $\overline{X}$ tolerance is permitted when σ is small, and vice versa.

It is hoped that eventually the firing delay measurements afforded by Test Set Mk 173 will permit test firing to be run at the all-fire height, thereby obtaining specific numerical information upon each sample expended instead of the 50 percent misfires situation which is inherent in the Bruceton and Frankford statistical procedures. The accumulation of suitable experience and appropriate methods for handling the test data is mainly a matter of time.

Section 2.—Output Tests

The output tests described in this section are much more varied in their nature and complexity than are the input tests of the preceding section. This difference may be attributed to the fact that the output of a firing train component may be required to produce a wide variety

of effects: to detonate a lead or booster by shock; to do mechanical work in driving a firing pin; to initiate a detonator by shock, flame, or hot particles; to ignite a delay by flame and hot particles; or to lock a train in the armed position by moving detents or expanding confining walls.

It is pointed out that output testing is fundamentally simple and direct, since an evaluation number is usually obtained on each sample. This is in contrast to most input tests where the information is of the less valuable "go, no-go" variety.

Initiators of Booster-type Explosives (Detonators and Leads)

Output tests for detonator type components are generally based on an attempt to measure the brisance or the peak pressure of the shock wave. The common tests for detonators are practically all applicable to each of the three main varieties, namely, stab detonators, electric detonators, and flash detonators. However, for some of the tests, considerable ingenuity may be required to accomplish the desired adaptation.

Stab detonators. Stab initiated detonators may be tested for output by means of Test Set Mk 136, mentioned in the preceding section (page 9–4). This test is accomplished by the use of standardized lead disks which are mounted below the sample detonator. The plastic detonator holder, shown in figure 9–15, serves as a combination firing pin guide, detonator mount, and lead disk mount; the entire assembly is mounted on the anvil of Test Set Mk 136. Detonation of the sample causes perforation of the lead disk with an irregular hole which has an area more or less proportional to the brisance of the detonator. The area of the hole may be measured by use of a shadowgraph apparatus or by some simple photocell equipment such as that described in reference (38). Some typical lead disk measurements are reported on pages 4–13 and 4–14. Lead disk tests are seldom applied to electric or flash detonators unless a particular test set-up permits ready mounting of the lead disk.

Electric detonators. Electrically initiated detonators may be tested by copper block or bent nail methods for rough comparisons in the field. These tests are seldom used for stab or flash detonators unless specifically called for. The bent nail test is described in reference (39). Ordinary wire nails of specified size are attached to the side of the sample detonators by tape or by wiring in place. The detonator is fired and it bends the nail into a "V" form, the sharpness of the bend being taken as a measure of the strength of the detonator. This simple and unsophisticated test has long been used, but it affords very little quantitative information.

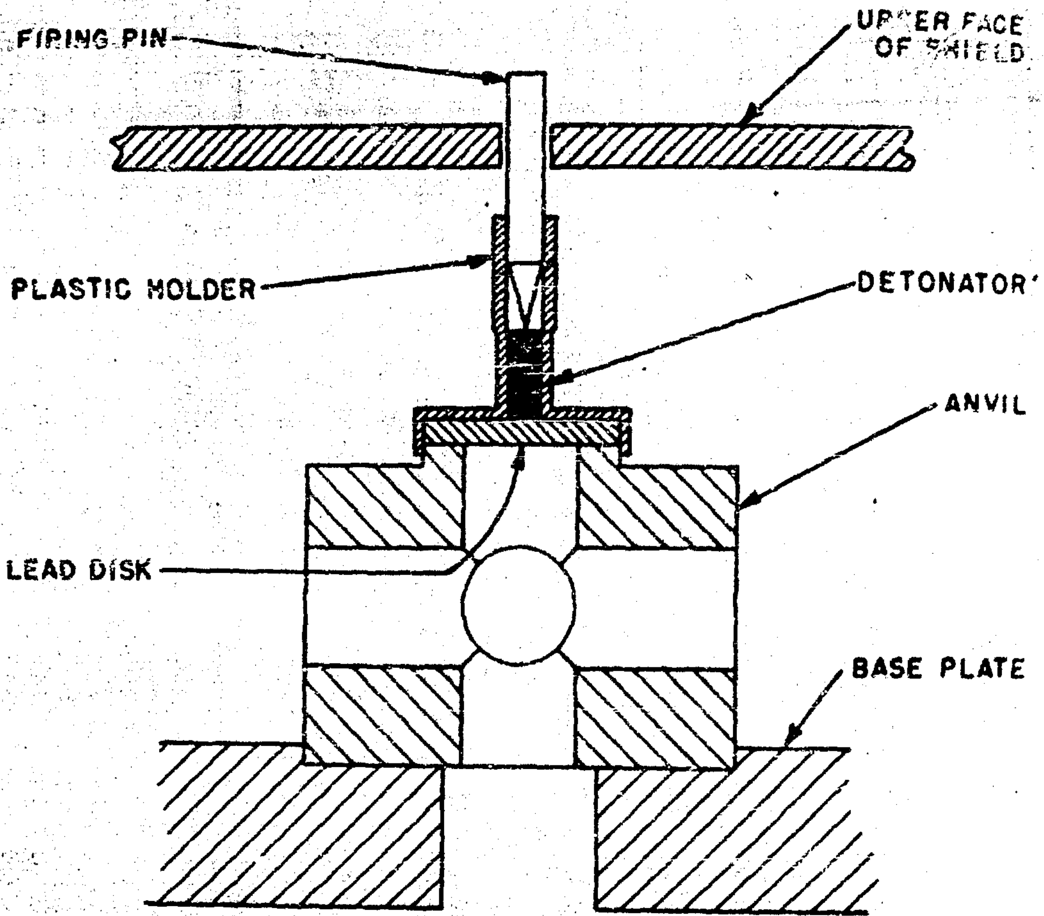


Figure 9–15. Detail of Lead Disk Mounting Below Detonator in Plastic Holder.

The copper block test is comparable to the bent nail test in simplicity. In this test, the detonator is fitted snugly into a drilled axial hole at the center of a copper cylinder or block. The outer diameter of the cylinder is measured accurately before detonation and again after detonation. The detonator explosion expands the block by a readily measured amount, and the magnitude of this enlargement is taken as a measure of the detonator output. Some typical copper block test results on flash detonators are recorded on page 4–7 under Output and in reference (41). This test, like the lead disk test, is based on the permanent deformation of a soft material and may or may not be a linear measure of detonator output.

Electric detonators are more frequently tested in the "sand bomb" apparatus. Flash and stab initiated detonators may also be tested in the sand bomb if appropriate initiating devices are provided. The sand bomb consists of a rugged chamber which may be loaded with a known weight of quartz sand packed firmly around the sample detonator. The original granulation of the sand is determined before

the test by sifting out all particles which pass a 20-mesh screen and all which are retained on a 30-mesh screen. After the detonation, the sand is sifted again to determine the percent crushed enough to pass the 30-mesh screen. Thus, the original granulation is all larger than 30 mesh, but after detonation a measurable portion is crushed enough to pass through the 30-mesh screen. In general, it is found that the percent of sand crushed is a linear function of detonator strength so long as the crushing does not exceed 20 percent of the total sand charge. Sand bombs of various capacities are built to cover the range of detonator strengths usually encountered without operating in the non-linear range. Capacities of 100, 200, 400, and 500 grams are standard. References (39) and (40) describe these tests in greater detail. Typical sand bomb test results are recorded in references (41) and (42) as well as on page 3-53.

Reference (42) points out a tendency for the test results to be dependent upon temperature. Otherwise, the sand bomb test appears to be fairly reliable but exceedingly time consuming.

Flash detonators. No tests specifically intended for flash detonator output measurement have been developed. The general detonator tests described in paragraphs immediately following are applicable to flash detonators where suitable initiation can be provided.

Recent detonator tests. A number of detonator output tests have been developed in recent years to afford better quantitative data than may be obtained by the tests described earlier. These more recent tests include (*a*) the Hopkinson Bar, (*b*) the Stauchapparat, (*c*) Gap Tests and (*d*) Insensitive Explosive Tests. Of these, perhaps the most promising is the Hopkinson Bar.

The Hopkinson Bar test for detonator output has been copiously described in postwar reports. Reference (43) describes the form of this equipment which was used in England during World War II. Reference (44) is an analysis of the performance of the Hopkinson Bar when used with electrical auxiliary equipment described later. Reference (45) describes an application to underwater explosions, but is of interest for its illustration of typical test results. References (46) and (47) describe recent experimental work on modifications of the Hopkinson Bar.

The Hopkinson Bar measures the peak pressure applied to the end of a steel bar by the explosion of a detonator adjacent to the bar end. In general, when a detonator is fired adjacent to the end of a steel bar, a compression wave results from the sudden application of pressure and this wave has an amplitude proportional to the peak pressure applied to the end surface of the bar and a duration equal to

that of the applied pressure. This compression or longitudinal wave is transmitted along the bar at approximately the velocity of sound in steel (16,000 ft/sec) and arrives in a few microseconds at the remote end of the bar. Such a wave is normally reflected from the free end as a tension or rarefaction wave which returns back along the bar toward the detonator end. In the Hopkinson Bar Test apparatus, this process is disturbed by the introduction of a discontinuity in the bar a short distance from the free end. In other words, the pressure bar is made up of two sections; a long section which is the main pressure bar, and a short section which is the "timepiece". The timepiece has one finely ground and polished surface which may be wrung into contact with an equally finished surface at the end of the main pressure bar. The timepiece is thus held in place by the surface forces as is the case with Johannsen gauge blocks. This cleavage plane does not interfere with the propagation of the original compression wave. However, when the wave is reflected from the free end of the timepiece as a tension wave, the surface forces are wholly insufficient to transmit the tension across the cleavage plane, and hence a portion of the wave is trapped in the timepiece. By choosing the proper length of timepiece relative to the wave length of the compression wave, the timepiece is caused to trap an amount of energy which is proportional to the peak pressure of the wave. The timepiece separates from the pressure bar with a velocity which is a measure of the peak pressure, and this velocity is determined by receiving the timepiece in a ballistic pendulum.

The foregoing description relates to the form of the equipment covered in reference (43). This practice has been modified to measure the velocity of the timepiece directly by means of an electronic counter-chronograph. This equipment is shown in figures 9–16, 9–17, and 9–18. Figure 9–16 shows the ballistic pendulum form of the equipment using a tapered pressure bar. Figure 9–17 shows the corresponding cylindrical pressure bar, and figure 9–18 shows the adaptation to electronic velocity measurement.

Early in the development of the Hopkinson Bar for fuze detonators, it was found that no engineering material was suitable for use in direct contact with the detonator. Calculated detonation pressures are of the order of one million pounds per square inch, and no known metal will withstand such a pressure nor deform linearly in this range. Plastic (non-linear) deformation of the pressure bar material would not only damage the bar but also give an erroneous deflection of the ballistic pendulum. Two possible alternatives exist for avoiding damage to the bar.

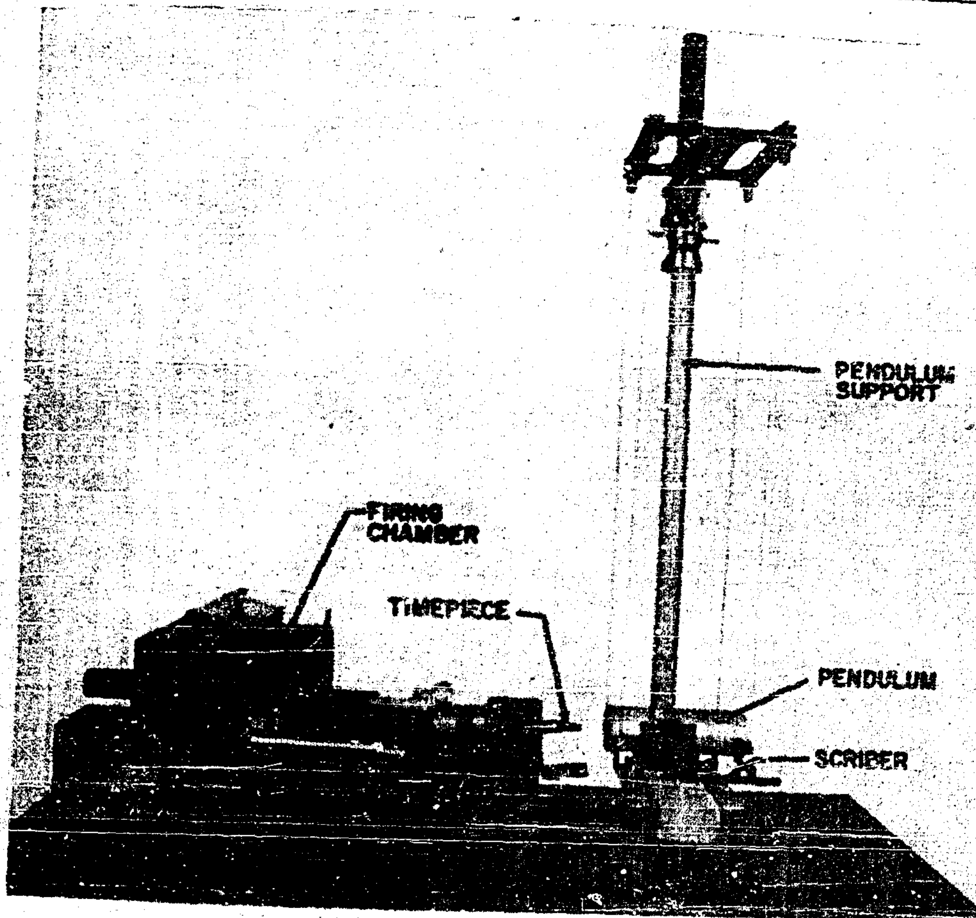


Figure 9–16. Tapered Hopkinson Bar for Radial Pressure Tests.

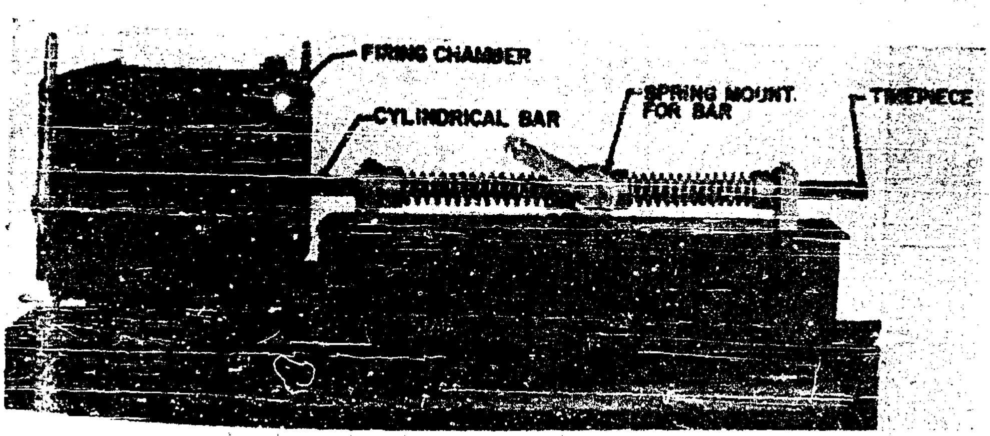


Figure 9–17. Hopkinson Bar for Longitudinal Pressure Tests.

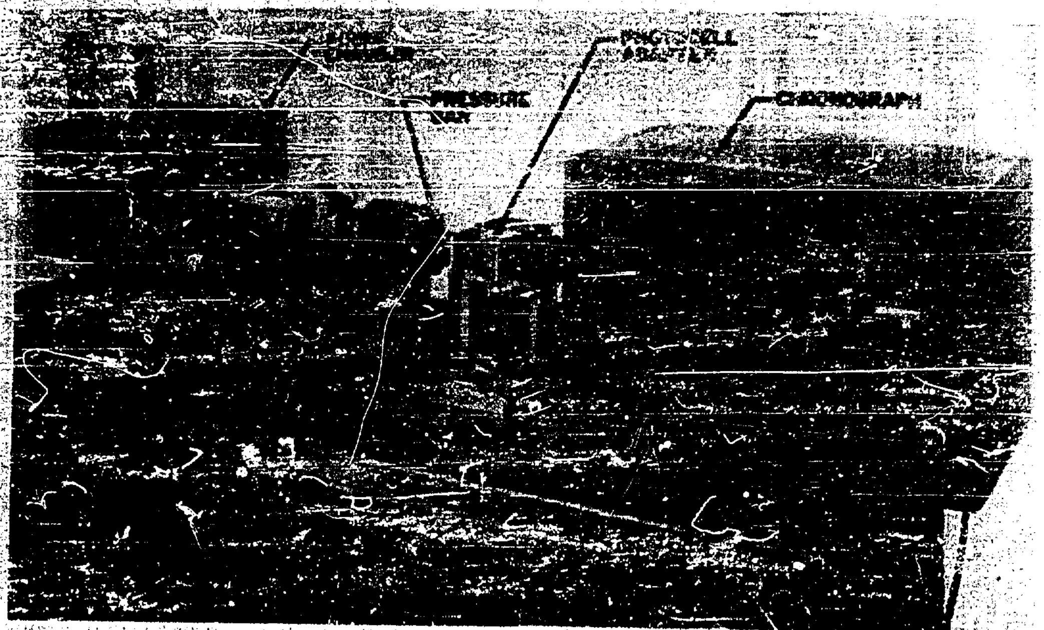


Figure 9–18. Hopkinson Pressure Bar Modified for Direct Velocity Measurement on Timepiece.

The first is the method used in the British models, which involves interposing a standardized pellet of refractory material between the detonator and the bar. The standard pellet of mixed asbestos and magnesia attenuates the pressure at the end of the bar to a value low enough for a linear bar response. This pressure might be of the order of 200,000 psi. It is evident that the amount of attenuation of the pressure wave will depend greatly on the characteristics of the pellet.

The second method is to simply space the detonator a known distance away from the surface of the bar and to depend upon the normal attentuation of pressure with distance. This method has the advantage that the pressure is attenuated in a reproducible fashion but is open to the objection that it affords no protection from high velocity fragments of the detonator casing. The equipment described in reference (47) may be used either with air gaps or with cheap spacing pellets of plastic or resin.

Since the absolute maximum pressure at the detonator cannot be recorded, but only a fraction of the pressure, it appears that the Hopkinson Bar is most reliable as a comparison instrument as far as fuze detonators are concerned. On a comparative basis only, its use may simplify design and produce a rugged and reliable quantity control instrument. The finely finished timepiece may be discarded, as well as the fragile ballistic pendulum, and a sturdy rigid pendulum assembly may be substituted. A steel sphere resting lightly against

the end of the pressure bar serves as both timepiece and pendulum. The large bars of the British design may be discarded and a short steel or stellite bar of ¼ to ⅜ inch diameter may be used. This modification leads to the design shown in figures 9–19 and 9–20 which

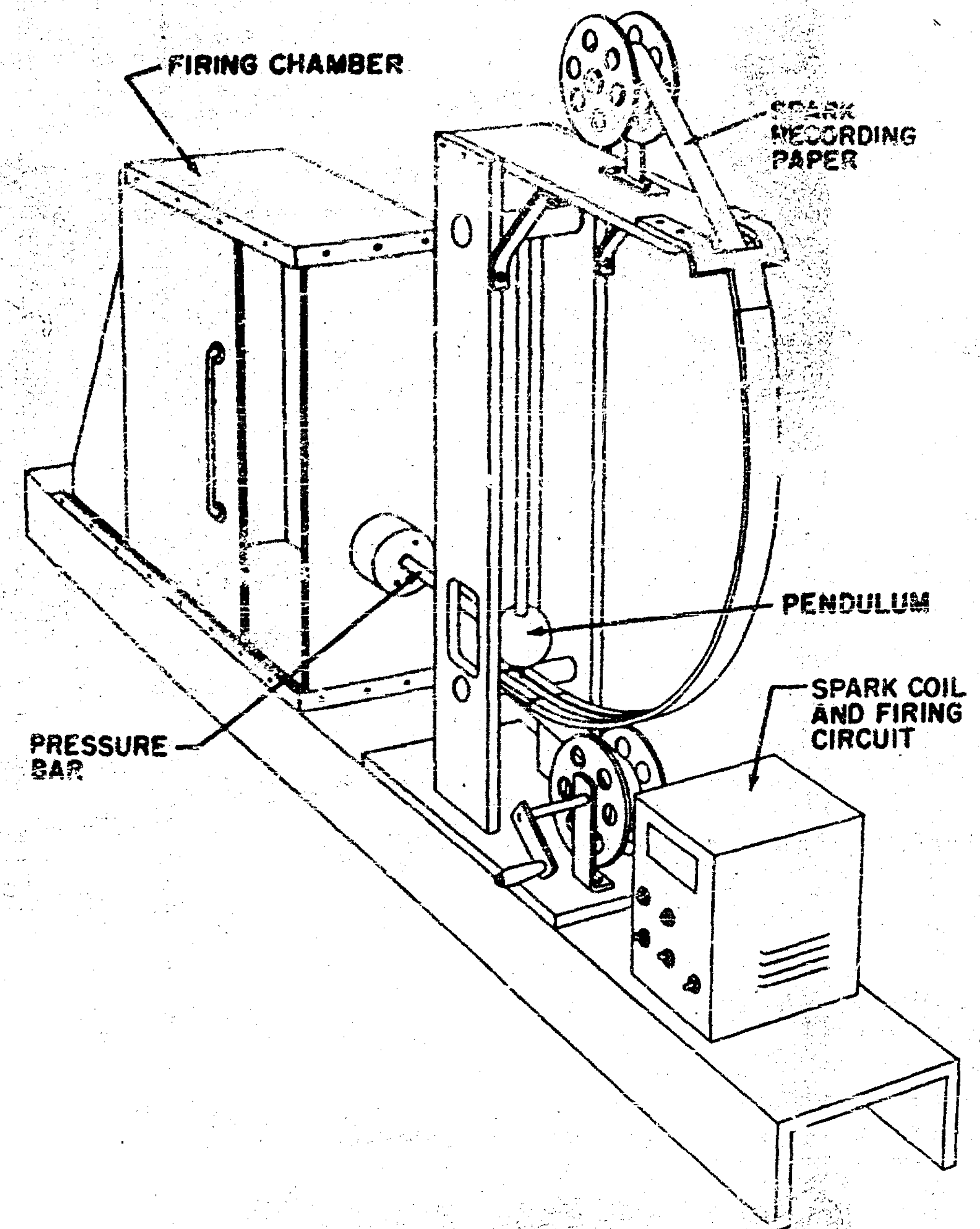


Figure 9–19. Proposed Design of Pressure Bar Tester. General Arrangement.

Note. The amplitude of pendulum swing is recorded by passing a spark from an electrode on the end of the pendulum through the recording paper strip, and measuring the length of the trace left on the paper.

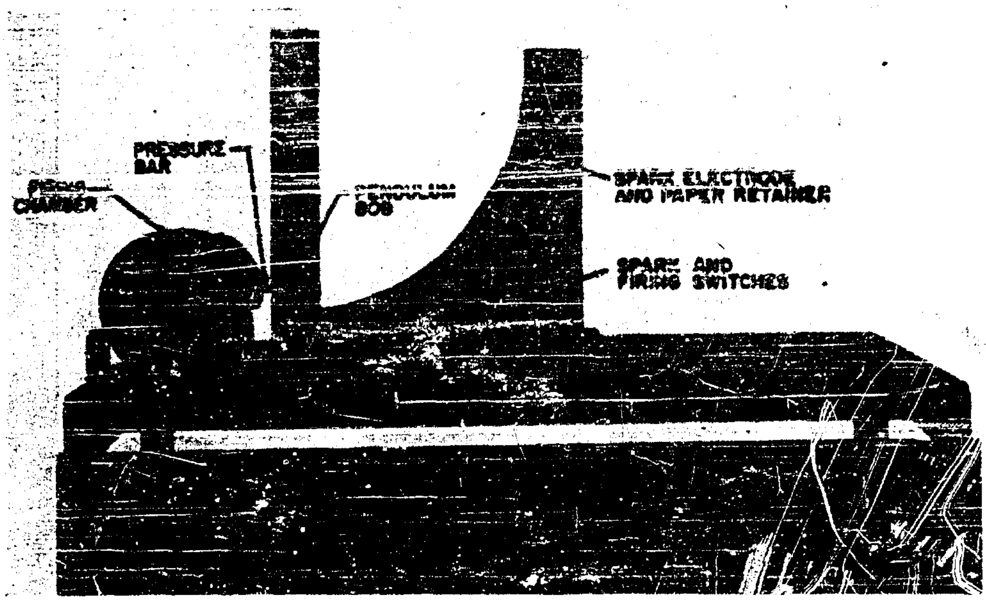


Figure 9–20. Experimental Model of Simplified Hopkinson Bar. Spherical Pendulum Bob Driven Directly by Bar.

has proved quite reliable and reproducible as a quality control device.

The Hopkinson Bar has sometimes been used with electrical strain measuring equipment to measure the actual instantaneous compression in the pressure bar material. The discussion in reference (44) is largely concerned with the electrical Hopkinson Bar and its probable errors, with particular reference to capacitive strain measuring devices. The capacity strain gauge has been applied in several British pressure bar designs and has been used in several forms. In one case, the measuring capacitance is that between the end of the pressure bar and a fixed insulated plate spaced a few thousandths of an inch from the flat end of the bar. In another version, the measuring capacitance is between the cylindrical surface near the end of the bar and an insulated cylindrical electrode concentric with the bar and extending beyond the free end of the bar.

In the first case, the change of capacity when the end of the bar moves toward the fixed plate is a measure of the compressive strain in the bar; while in the second case, the bar moves further into the cylindrical condenser, thereby increasing the effective plate area rather than changing the plate spacing. In both cases, the change in capacitance generates a signal voltage which may be photographed on the screen of a cathode ray oscillograph. Because of a complicated phenomenon of frequency dispersion in the bar, the signals generated by the capacitive strain gauges are only reliable when the bar is short and small in diameter relative to the length of the compression wave

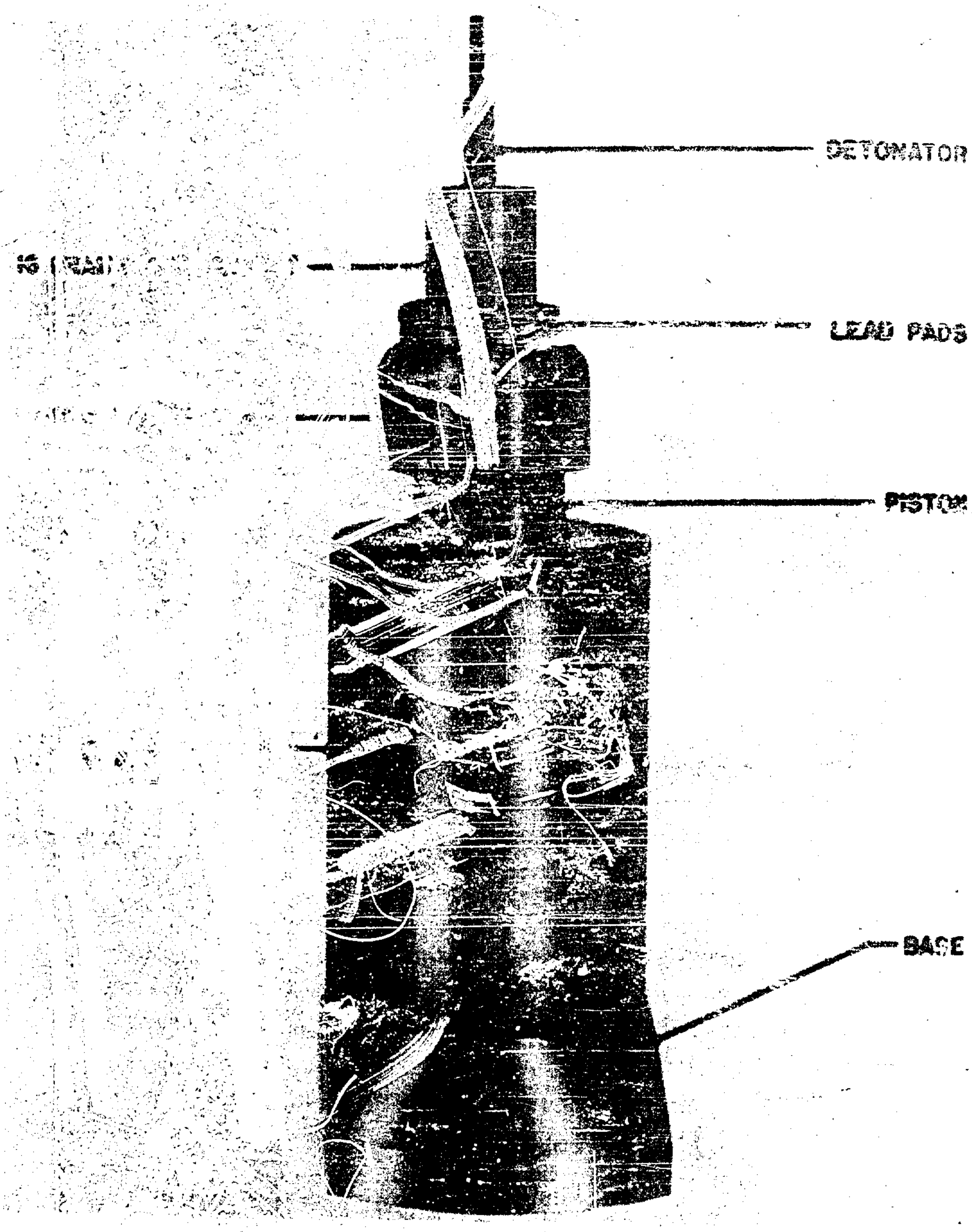
At present, work is underway ... wire resistance strain gauges for the capacitive strain gauge ... development is still in the early stages.

The Stauchapparat, Gap T... Insensitive Explosive Test are all subject to one major objection. This objection is based on the fact that measurement is made in terms of the initiation of a second explosive component, and thus the ... of the measurement is completely dependent upon ... constant sensitivity level for the second explosive. In general, ... a constant sensitivity for the acceptor explosive ... there would be less need for the various ... described in section ... this chapter. However, it ... of measurement has the appeal that ... to some degree, and hence these tests are still used.

The insensitive explosive test is perhaps the oldest of the three. In this test, the detonator or ... against a block of explosive which presumably has a constant sensitivity. The receptor explosive is a mixture of TNT and iron oxide, and the greater the proportion of iron oxide in the mixture the less the sensitivity. ... running the test, the acceptor mixture which would be initiated 50 percent of the time by the sample detonator may be determined by methods resembling the Bruceton procedure, or the Frankford procedure if sufficient samples are available.

Gap tests have a superficial resemblance to the insensitive explosive tests. In the gap test, the spacing between ... sample and the acceptor explosive is most frequently varied, although other parameters may be chosen, such as the axial misalignment between charges or the ratio of donor ... charge diameter to acceptor diameter. These variations of ... configuration may be construed as variations in the sensitivity of the acceptor, just as the varying proportions of iron oxide in the acceptor explosive in the insensitive explosive test are considered to vary the sensitivity.

It should be pointed out that in such tests as the gap test, the measurement may be considered either as an output measurement for the first (donor) explosive or as a sensitivity test for the second (acceptor) explosive, depending upon which explosive is considered to be constant in its performance. When the gap test is used as an output measurement for the det... the completeness of detonation of the acceptor is the dependent variable ... reported. By varying the gap in small increments, it is possible to progress through no acceptor initiation, low order ... high order initiation as a function of gap length. The ... of low order initiation of the acceptor versus high order ... may be based on the



F...u... 9-21. *Steuchapparat, Assembled.*

expa... ...er block in which the acceptor is mounted, by ... ...e residues on the copper block, or by direct ... ...the detonation velocity in the acceptor. Reference (48) ... gap test data obtained in recent years, and section 3 of ... (page 8-11) throws additional light upon some of the limi... ...

T... ...at is a crusher gauge type of apparatus originally dev... ...any as a means for comparing the brisance of vari... explo... ...hen initiated by a standard detonator. It wa...

found that the indicated brisance of an explosive sample was a function of the strength of the initiating detonator; therefore, the original purpose of the equipment has been discarded, a standardized acceptor explosive chosen, and the device developed as an output test for fuze detonators. Reference (49) recounts the story of the Stauchapparat development and tabulates considerable test data wherein the performance of the Hopkinson Bar and the Stauchapparat are compared. The present form of the Stauchapparat is shown in figures 9–21 and 9–22, which indicate that the principal components

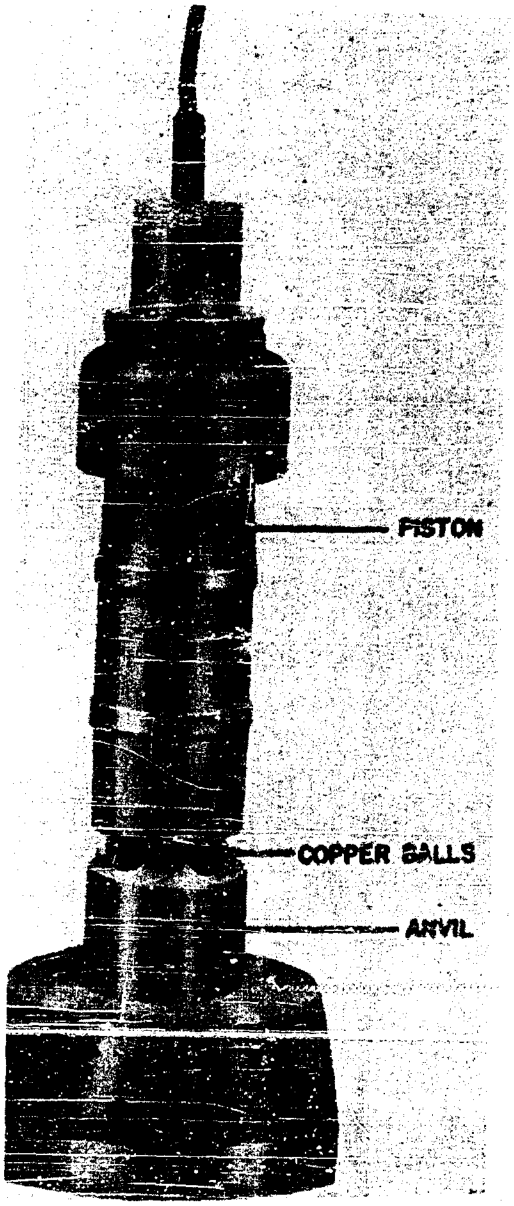


Figure 9–22. Stauchapparat, Without Protective Cylinder.

of the device are (*a*) an anvil upon which rest (*b*) three copper balls of known hardness and diameter, (*c*) a piston which rests on top of the copper balls and transmits the impulse of the explosion to the balls, (*d*) a guiding cylinder surrounding the piston, and (*e*) a protective cap at the top of the piston to resist damage to the piston by the explosion of the 16 gram TNT pellet which is the standard acceptor explosive in this device. The explosion of the TNT pellet causes the copper balls to be deformed, and this deformation is taken as a measure of the completeness of detonation of the TNT pellet, which in turn is a measure of the output of the sample detonator. This device gives results that check qualitatively with Hopkinson Bar and sand bomb measurements and hence would serve as a fairly satisfactory field test instrument. For work in the field, this equipment has the advantage that it requires no external sources of power except that required to initiate the detonator. For laboratory use, the Stauchapparat suffers the disadvantage that appropriate barricades must be provided to protect personnel from the explosion of the 16 gram TNT charge.

Other tests for detonator output have been investigated in the past but are seldom used now. New types of tests are still under development, such as improved gap tests and measurements of detonation velocity at various points along the detonator, or measurement of line radiation from inert gases when subjected to detonation pressures.

Initiators of Primary Explosives and Pyrotechnics (Primers)

Stab primers. The output of stab initiated primers may be measured by the lead disk test described in connection with Test Set Mk 136 on page 9-31.

However, the brisance of stab primers is generally quite low, and it is not usual for the lead disk to be perforated. It is, therefore, necessary to measure the indentation made in the lead disk rather than the area of the hole. Some typical lead disk indentation measurements are reported on pages 3-3 and 3-9.

Stab primers may also be tested in Test Set Mk 175, the "Gas Volume and Impulse Apparatus," which is described in references (50) and (51) and shown in figure 9-23.

Test Set Mk 175 consists principally of (*a*) a mercury reservoir, (*b*) an upright capillary tube, and (*c*) a firing chamber. When a primer is fired in this test set, the hot reaction products build up pressure in the firing chamber. This pressure is communicated to the upper surface of the mercury in the reservoir, and this, in turn, causes a column of mercury to rise in the capillary tube. The

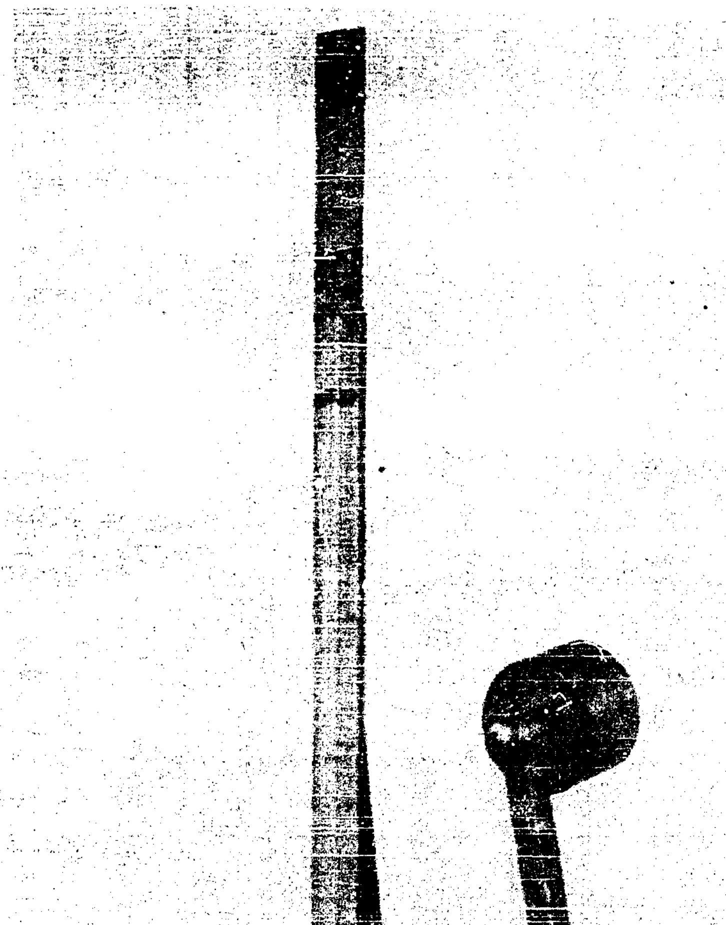


Figure 9–23. Test Set Mk 175 Mod 0.

mercury column rises momentarily to a considerable height in the tube and then settles down to a sustained height. By comparison with a graduated scale back of the capillary tube, both the maximum and the steady deflections of the mercury column are measured; the first being recorded as the primer "impulse" and the latter as the "cold gas volume."

While Test Set Mk 175 may be so calibrated that the actual gas volume corresponding to the change in mercury column height can be computed, this is not essential when the apparatus is used as a comparison device. It has been found that the cold gas volume as computed from measured column heights is in good agreement with calculated volumes of reaction products at corresponding temperatures and pressures, so the apparatus is at least as accurate as the assumptions involved in computing the volume of reaction products. When primers of different explosive composition are to be tested, the gas volume and impulse apparatus may be considered suitable for rough comparison purposes only. The equipment appears suitable for quality control of a particular primer type, since the indications follow the trends detected by the more elaborate equipment described later. Thus, when other test devices show a loss of output, the impulse reading of Test Set Mk 175 decreases in about the same ratio; apparently the impulse indications have some real significance. Typical test results are reported in reference (51) as well as on pages 3-9, 3-20, and 3-21. It should be noted that Test Set Mk 175 is applicable to percussion primers as well as stab primers, and could readily be adapted for electric primers if desired.

Other apparatus for measuring the output of stab primers has been developed in recent years. Test Set Mk 172 Mod 1 and proposed Test Set Mk 180 Mod 1 are both applicable to stab primers, although they were originally developed for percussion and electric primers. Both of these test sets are described in paragraphs immediately following. No typical test data for stab primers have been recorded with these instruments as yet.

Percussion primers. Output tests for percussion initiated primers may be performed with Test Sets Mk 172 Mod 1, Mk 173, Mk 175, and proposed Mk 180 Mod 1. A discussion of these test instruments follows.

Test Set Mk 172 Mod 1 is a ballistic pendulum of unconventional design. In the first place, the pendulum is a torsional pendulum, deflecting in a horizontal plane against the restraint of a piano wire that is twisted by a torsional force instead of deflecting in a vertical

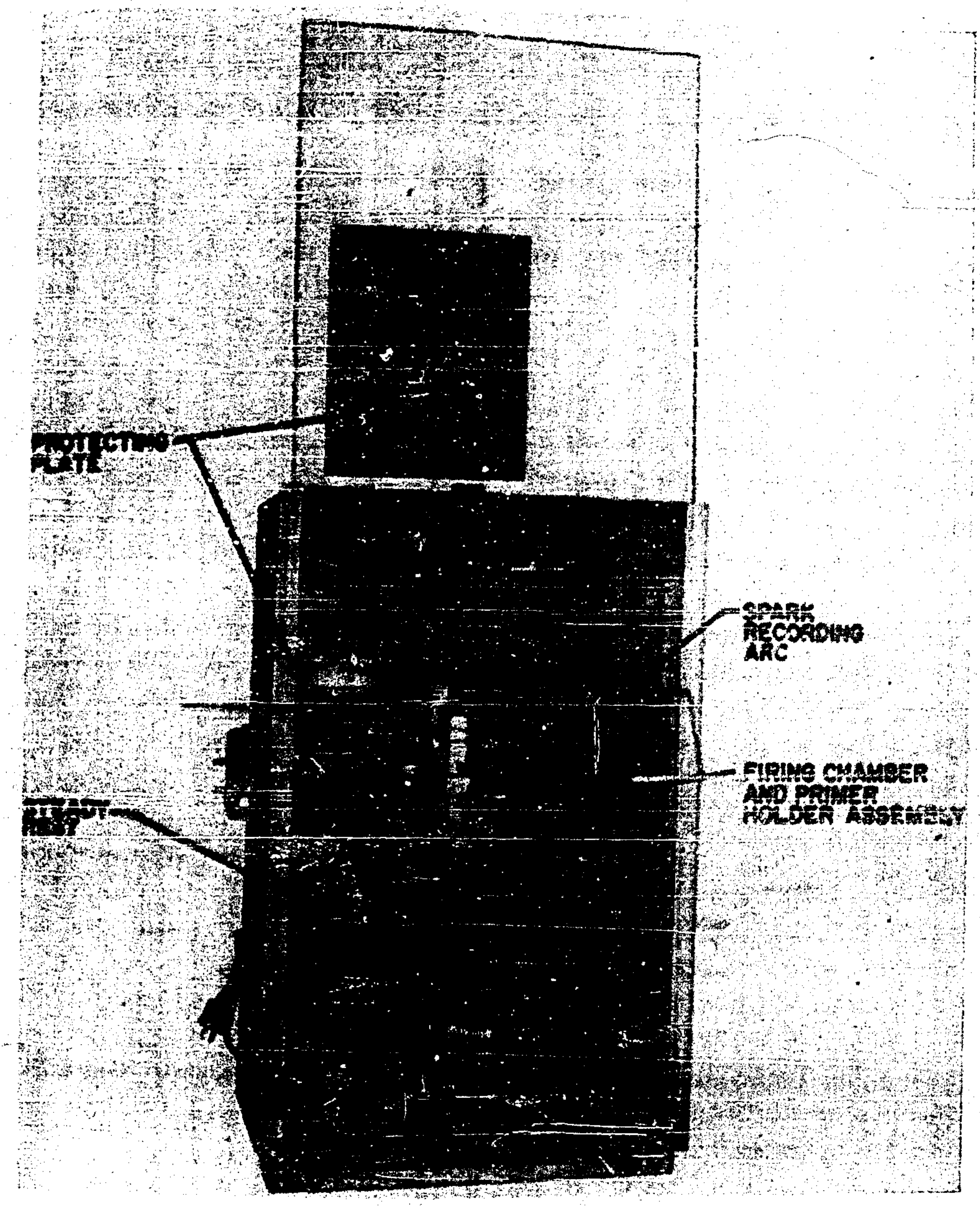


Figure 9–24. ***Test Set Mk 172 Mod 1, for Percussion, Stab, and Electric Primers.***

plane against a gravity restoring force. In the second place, the component to be tested is mounted in the pendulum bob and produces deflection by the reaction of the jet of rapidly moving gases which it releases. The maximum angular deflection of the torsional ballistic pendulum is a measure of the momentum of the gases and particles emitted by the sample primer. The deflection is recorded by means of a spark and waxed tape mechanism.

Figure 9–24 depicts the general features of the instrument, and

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references (52) and (53) report the performance and theory of operation. The primer gases are emitted through a standardized orifice which directs the flow and improves the efficiency of the energy utilization of the system. Because of the unknown efficiency of the arbitrarily standardized orifice, Test Set Mk 172 is considered useful for comparative purposes only; but the accuracy with which output comparisons may be made is very great with this instrument. It is found, for example, that when percussion Primers Mk 101 with graduated loads are tested in this equipment that the maximum angular deflection is a linear function of charge weight (of a given mixture) and that an increment of 1 milligram of charge in a 21 milligram load results in about 1 centimeter change in peak deflection. These data permit accurate surveillance studies of primer output and provide a reliable method of checking quality on the production line.

A number of interesting problems were encountered in the design of Test Set Mk 172. In the application of the equipment to percussion primers, it became necessary to strike the primer with an appreciable blow to initiate it; however, this blow could not be delivered from outside the system without causing a deflection. This problem was solved by the incorporation of firing pin and spring in the pendulum bob, or rotating assembly. Residual deflections of the pendulum due to the motion of the firing pin and spring were cancelled out by the use of a dual firing pin and spring system such that the motion of the principal firing pin was at all times balanced by the motion of an auxiliary firing pin traveling in the opposite direction. Residual deflections with dud primers are thus reduced to less than 1 millimeter, or less than ½ percent of full scale deflection for Primer Mk 101.

Test Set Mk 172 Mod 1 is applicable to stab initiated primers by a simple change in firing pin design, and to electrically initiated primers by the substitution of a different firing chamber to accommodate the larger primer body.

Test Set Mk 173 Mod 0, which has already been mentioned in connection with sensitivity tests, also incorporates a means for a comparative output measurement in terms of the heat delivered to the junction of a thermocouple which is directly in the path of the hot reaction products.

This thermocouple for percussion primer output comparisons is a ruggedly built unit which can withstand thousands of primer explosions without loss of accuracy. It is constructed by lap welding No. 24 gauge chromel and alumel wires together to form a continuous straight wire. The weld is filed to the diameter of the original wire. The welded assembly is silver soldered to heavy copper support posts so that the finished unit consists of two heavy copper posts joined b

about a ½ inch length of chromel-alumel thermocouple wire with the junction midway between the posts. The thermocouple units are reproducible to within about ±5 percent at worst and may be filed and adjusted to closer tolerances if necessary.

The relatively heavy gauge of the thermocouple wires, necessitated by durability considerations, results in a system which does not follow the instantaneous temperature variations in the primer flame. Instead, the thermocouple responds as an integrating device, the thermocouple emf increasing according to the integral of the temperature time function of the flame. The geometry of the system is such that the primer gases must flow past the thermocouple in order to escape. Therefore, indirectly, the peak emf of the thermocouple is a measure of the gas temperature times the quantity of gas flowing past the thermocouple. Thus the instrument is capable, at least roughly, of measuring relative heat outputs.

Since the thermocouple emf is exceedingly small, it is necessary to amplify the signal to a level suitable for the operation of a peak holding voltmeter. This is accomplished by means of a breaker-amplifier circuit which is described in references (13) and (14). The combination of breaker amplifier and peak holding voltmeter is capable of full scale deflection of a 200 microampere meter movement for a 50 microvolt signal from the thermocouple. Additional ranges are provided to permit operation at reduced sensitivity when larger primers are being studied. Relative outputs of fuze primers can thus be stated in terms of equivalent microvolts delivered by the thermocouple to the amplifier input.

It has been found that the thermal output measurements afford a convenient method for comparing the effectiveness of various experimental explosive mixtures, as well as for detecting deterioration of primer output during surveillance. Some typical thermocouple data are tabulated in reference (54) and on pages 3–15 and 3–19 to 3–22, inclusive.

Test Set Mk 175, frequently used for quality comparisons of percussion primers, has been described earlier (pages 9–42 to 9–44) in this section under Stab primers.

Test Set Mk 180, modified for percussion primers, is a laboratory instrument for the measurement of the pressure developed by a primer explosion in a small sealed chamber. With this instrument, it is possible to measure the instantaneous pressure in the small chamber as it builds up during the explosion and as it dies down gradually during the cooling of the reaction products. Since the volume of

the chamber is known, it is possible to compute the maximum pressure which the primer will develop in any other volume, such as that in a fuze firing train. Except for the actual firing chamber and the method of initiation, this test set is identical with Test Set Mk 180 Mod 0, which is described in detail in this section under Electric primers (page 9-51). A description of this test set is presented in references (64) and (65).

Other tests for percussion primer output have been tried at various times in the past. An early version of the thermocouple test is reported in reference (16) wherein essentially the same thermocouple as that of Test Set Mk 173 was used but in conjunction with a fluxmeter galvanometer instead of a breaker amplifier and voltmeter. This apparatus proved difficult to use because of excessive drift in the fluxmeter and because of the integrating features of the fluxmeter. Instead of indicating the peak output emf of the thermocouple, the fluxmeter indicated the integral of the emf as a function of time. This necessitated a dual adjustment of the thermocouple sensitivity in that the thermocouple cooling rate had to be controlled as well as the peak emf for a given flame pulse. This arrangement proved to be rather impractical where close tolerances in thermocouple response were desired.

Measurement techniques based upon integrating the current flow between a pair of electrodes placed in the path of the incandescent gases emitted by the primer have been found to be unsatisfactory. In such techniques, it is assumed that the ionization current is more or less proportional to the intensity of the flame and that the duration of flow will equal the duration of the flame. The current is allowed to charge a condenser to a voltage proportional to the current-time integral, and the resulting condenser voltage is measured with a vacuum tube voltmeter. It has been found that atmospheric conditions and the alkali metal content of the charge have more influence on the measurement than does the strength of the explosion.

Another approach to primer output measurement was used to some extent at Picatinny Arsenal, according to the reports listed as references (55) and (56). In this case, the primer light output was measured by means of a photoelectric tube and cathode ray oscillograph. The output of the photo tube as a function of time was displayed on the cathode ray oscillograph screen, and the screen was photographed to obtain a permanent record. Insofar as the radiated light from the primer flash may be considered a measure of the output of the primer, this type of equipment would provide a useful means for comparing primer outputs. Whether or not the light radiation from the primer flash is as good an index to the primer output as the heat transferred

to a thermocouple is not known at present, but should be determined at some future date. The calibration of photoelectric tubes for short light pulses should be more readily obtained than the corresponding calibration of thermocouples of the type used in Test Set Mk 173. Even such difficulties as variation in spectral response between production photoelectric tubes could probably be overcome by appropriate calibration methods if the basic measurement is proved to be reliable. Obviously, this technique could be readily extended to stab and electric primers by simple design modifications.

Measurement of percussion primer output in terms of the delay obtained with a pyrotechnic delay pellet is occasionally resorted to. It is found that high output primers tend to shorten the over-all delay of a black powder delay element below the nominal delay value, while weak primers tend to produce longer delays. Reference (54) includes a tabulation of delay times measured with various percussion primers in conjunction with a standard delay pellet. In general, the delay time and the thermocouple measurement vary in an inverse functional relationship, as may be seen from table 3-8 (page 3-19). Instrumentation techniques for delay measurements are described in reference (63).

It has occasionally been suggested that primer outputs be compared on the basis of the intensity of the sound of the explosion. It presumably would be possible to set up a sturdy microphone in the vicinity of the primer and to measure the maximum sound intensity incident on the microphone by means of an amplifier and transient peak voltmeter or oscilloscope. While this type of measurement has not been attempted for fuze primers as far as can be ascertained, it appears to be an approach which would be worth investigating, for it is identical in principle to blast pressure measurements which are made on large explosive charges. However, it might be expected that such tests would be best performed in an open area rather than in an enclosed firing chamber, in order to minimize the disturbing effects of acoustic reflection.

Electric primers. Output tests for electric primers may be performed with Test Set Mk 172 Mod 0, described in this section, under Percussion primers (page 9-44), with Test Set Mk 148 Mod 0, which is a sand bomb apparatus; with Test Set Mk 180 Mod 0, the primer pressure bomb apparatus; and occasionally with copper blocks. No information is at hand regarding the applicability of the thermocouple feature of Test Set Mk 173 Mod 0 for electric primer output comparisons, but it appears probable that a more massive design would be necessary.

Test Set Mk 148 Mod 0 sand bomb apparatus is shown in the

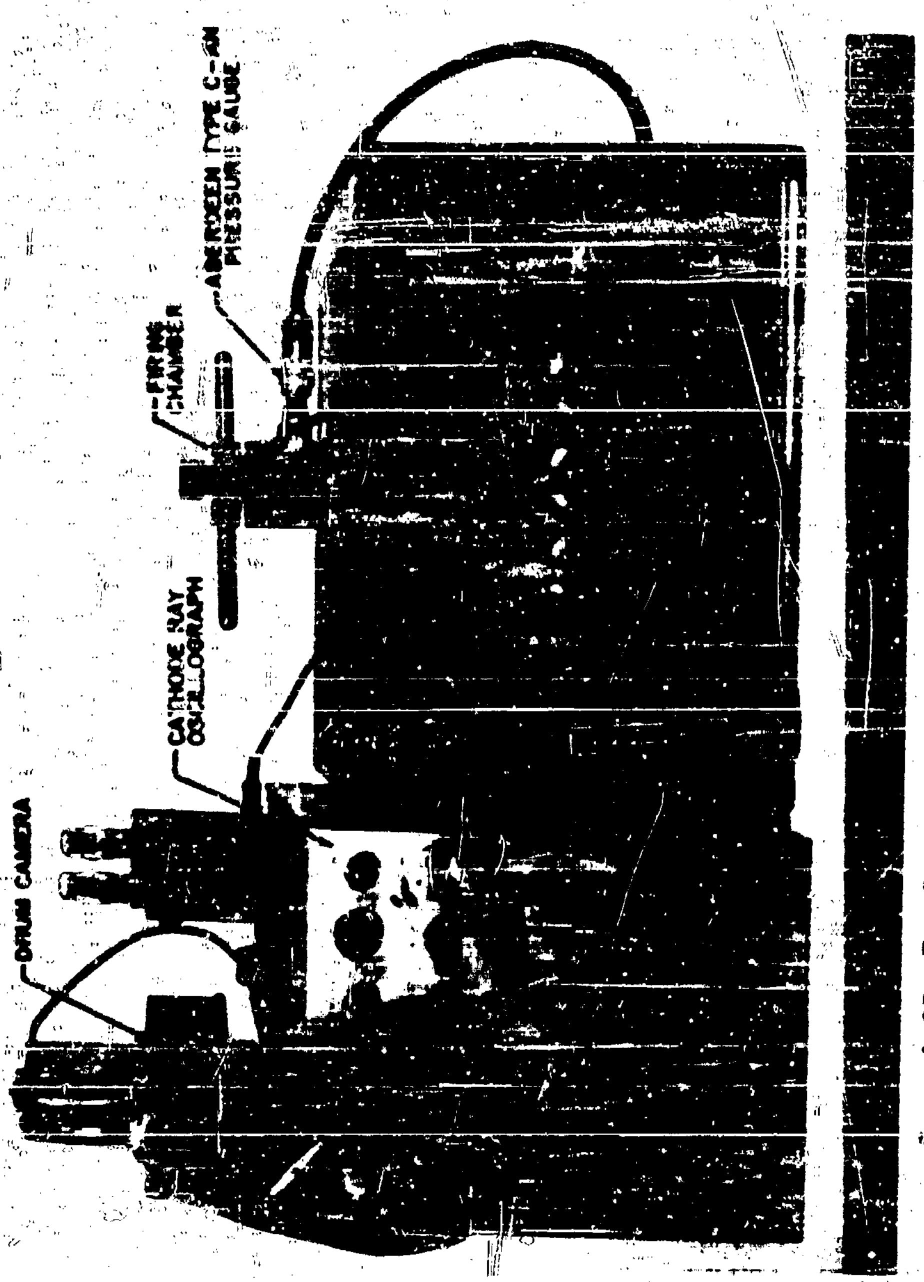

Figure 9-25. Test Set Mk 180 Mod 0 (Primer Pressure Bomb Apparatus).

drawings listed in reference (57). The general principles of sand bomb tests have already been described in this section (page 9–32).

Test Set Mk 180 Mod 0 is perhaps the most reliable output measuring instrument for electric primers and merits a fairly detailed discussion. This apparatus consists of the primer pressure bomb and associated electronic accessories. It permits measurement of the instantaneous pressure as a function of time in a small sealed chamber which contains the exploding primer. Figure 9–25 shows the general appearance of this apparatus as it is used for laboratory measurements of electric primer output. A complete description of the various components and their manner of operation is given in reference (58). Among the instruments discussed in the output measurement group, the primer pressure bomb and the ballistic pendulum are the only ones that attempt an absolute measurement of output, as distinguished from the comparative measurements afforded by the other test instruments. The Hopkinson Bar would approach this result if it were not necessary to use degrading pellets between sample and bar.

The Primer Pressure Bomb apparatus includes the following components: (*a*) the pressure bomb proper, with appropriate means for inserting and sealing the sample primer, (*b*) the pressure gauge, which is of the Aberdeen Type C–AN variety, (*c*) the strain gauge power supply, bridge, and amplifier, and (*d*) the indicator unit, which may be a cathode ray oscillograph with a drum camera recorder or a peak holding voltmeter.

The primer bomb proper is a small steel chamber of known volume and of such design that it may be tightly sealed against escape of the gaseous products of an explosion. Sealing is sufficiently good to permit retention of gas pressures of several hundred psi in a volume of about 1 cubic inch over a period of 24 hours, and yet the bomb may be readily opened for loading and unloading.

The pressure gauge used in the present model of the primer bomb equipment is the Aberdeen type C–AN elastic tube gauge described in reference (59). This gauge consists of a thin walled steel tube, closed at one end and open at the other end to the pressure source. A helix of resistance wire is wound about the outer circumference of the tube and bonded to the surface by a layer of cement or varnish which also serves as electrical insulation between the winding and the tube. When pressure is applied to the open end of the tube, the tube circumference increases proportionally and stretches the resistance wire winding. This causes a definite increase in the winding resistance, which may be measured to determine the magnitude of the applied pressure.

The strain gauge control unit houses the electronic circuits which convert resistance change, just mentioned, into an electrical signal suitable for display on the screen of a cathode ray oscillograph. The unit includes the remaining arms of the resistance bridge for which the gauge acts as the fourth arm. Appropriate bridge balancing controls, a 20 kilocycle carrier power oscillator to power the strain gauge bridge, and a sensitive preamplifier comprise the remainder of the circuits in the control unit.

The indicator unit is usually a modern high performance cathode ray oscilloscope such as the Tektronix Model 512 or the DuMont Model 304H. Associated with the oscilloscope is a drum camera of the type described in reference (60). An alternative type of indicator is a transient peak voltmeter which will read not only the maximum pressure developed by the primer but will provide immediate data without photographic processing. A report on this modification of the test set is in preparation.

Operation of Test Set Mk 180 has proved quite satisfactory. It is found that the peak pressure attained in the chamber is a reproducible function of the weight of charge of a given type of explosive. It is also found that a reliable reading of the static pressure in the chamber after the gases have cooled may be obtained, thus permitting an estimate of the volume of gas emitted by the primer.

Miscellaneous Safety and Output Tests

One type of test for firing train operation has not been mentioned in detail in the foregoing sections. This is the so-called "static detonator safety test" which is usually performed on the assembled firing train or a reasonable approximation thereto. In this test, the slider or rotor, which interrupts the firing train when the fuze is unarmed, is varied in position by small increments and the percent of successful initiations of the detonator by the primer is plotted as a function of the slider displacement. A similar plot may be made for lead initiation by the detonator. Such test may follow either the Frankford or the Bruceton procedures in their actual performance. Reference (61) describes some typical tests of this nature.

Another fuze or firing train problem is the safety of the assembly for handling or disassembly after tests. Where doubt exists as to safety, considerable information about the state of affairs in the fuze may be obtained by means of x-ray pictures, or where x-ray facilities are not available, the "Radium Camera" may be used. The latter consists simply of a photographic plate placed at one side of the fuze and a source of radioactive radiation at the opposite side. A description of this technique is given in reference (62).

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(49) NOLM 10665, **Stauchapparat (German Crusher Gauge) Laboratory Evaluation Tests of**, R. Suessle. February 1950.

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(51) NOLM 10507, **An Instrument for Measuring the Impulse and Gas Volume of Primer Explosions**, G. U. Graff. January, 1950.

(52) NOLM 10400, **Torsional Ballistic Pendulum for Testing Electric Fuze Primers**, J. B. Lord. September 1949.

(53) NOLM 10658, **Test Set Mk 172, Mod 1, for Output Comparison Of Percussion Initiated Fuze Primers**, C. J. Zablocki, J. N. Ayres and F. W. Hayward. December 1949.

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(57) Drawing List for Test Set Mk 148 Mod 0, LD 169937.

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(61) NOLM 10029, **Fuze (XBF-5A) and Inertia Switch (X-13B) for Lark--Design Proof Tests for Safety of**, A. H. Erickson. August 1949.

(62) BuOrd OP 1179, **Radium Camera Mk 2.** December 1944.

(63) NOL TN-310, **Apparatus for Measurement of Delay Train Firing Time**, E. F. Ward. October 12, 1950.

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(65) NavOrd No. 1500, **Transient Voltmeter for Use With Primer Pressure Bomb**, H. W. L. Street. July 11, 1950.

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Chapter 10

LOADING

Loading, as applied to ordnance explosive trains, generally includes the operations related to incorporating the explosive or delay charges into the ordnance device. Basically these operations consist of the following steps.

1. Segregating the correct amount of explosive or delay material.
2. Charging the material into the cavity or container to be loaded.
3. Consolidating the charge.
4. Securing the charge in its appropriate cavity within the device.

(In some instances, (3) and (4) are combined.)

The explosive train designer is interested in loading from the standpoint of (*a*) how to design explosive trains that can be readily loaded and (*b*) how to design loading tools.

Section 1.—Design Factors That Affect Loading Plant Operations

Since manpower is usually critically short during wartime, it is important that the explosive train designer strive for arrangements that facilitate loading. The design principles which tend to accomplish this aim are indicated below.

Segregating the Correct Amount of Charge

In segregating the correct amount of charge, it is usually preferable to use volumetric methods; they are quicker and more suitable for use with automatic and semi-automatic loading machinery such as pelleting presses and detonator loading machines. It is considered good practice for explosive train designers to specify a weight or volume and a density of charge with tolerances that are compatible with controlled volumetric charging methods.

Charging and Consolidating the Explosive Into the Cavity To Be Loaded

In general, there are four methods of loading an explosive train charge into a cavity.

The loose powder is poured into the cavity and consolidated in place.

A preformed pellet is dropped into the cavity and secured.

A preformed pellet is dropped into the cavity or container and consolidated in place.

A cased charge is secured in the cavity.

Method 1 is poor practice if the piece containing the cavity is large and heavy. Under these conditions, loading becomes hazardous and time consuming. This method is acceptable for loading small cased charges.

Method 2 is satisfactory if the pellet can be suitably secured.

Method 3 is the recommended procedure for loading small cased charges such as leads. This method is not suitable for highly sensitive explosives, since they are not readily pelleted.

Method 4 is highly recommended, particularly for cavities in large and heavy pieces. This method is also advantageous for sensitive explosive charges that may be near moving parts, since it tends to prevent dusting, which may cause prematures.

The preceding discussion emphasizes the importance of designing explosive trains so that charges to be loaded into cavities in large and heavy parts can be pelleted or precased. A typical example of a desirable loading procedure for a fuze lead charge is indicated below.

1. Pellet the lead charge.
2. Place the pellet in the lead cup.
3. Reconsolidate the lead charge in the lead cup with suitable support for the cup walls if necessary.
4. Secure the lead cup in the cavity in the fuze piece by some method such as that described under Army lead cup design, on page 6–5. From the standpoint of the loading plant, this type of loading is preferable to pressing the loose powder directly into an open cavity of the fuze body for the following reasons:

It simplifies tooling.

There is greater interchangeability of tooling from one fuze to another.

This procedure permits closer control of the loading density of charges.

It permits improved safety by (*a*) reducing the mass of parts usually being handled in the presence of loose explosives, (*b*) reducing the personnel exposed to the more hazardous operations, and (*c*) simplifying explosive train material contamination control.

The procedure simplifies inspection and testing.

It facilitates the use of automatic loading procedures.

It simplifies the scheduling and regulating of materials within the loading plant.

Securing the Charge

When special loading containers and fixtures that permit the consolidation of charges outside the ordnance device are used, this charge with its associated container must be secured in the device

so as to resist displacement or appreciable movement during handling, transportation, and service use. Reconsolidation, threaded assembly, crimping, and staking have been utilized to accomplish this job satisfactorily. These methods are considered superior to the use of cements, adhesives, and similar materials. Generally these operations are performed on automatic or semi-automatic machines, and in the case of crimping or staking it is necessary to provide metal precisely shaped and located so as to keep the charge from moving.

Normally, the most direct method of obtaining location control is by utilizing related surfaces of the appropriate part. In order to do this, however, the dimensional tolerances between the related surfaces to be used must be consistent with the allowable variations in the location of the crimp or stake relative to the explosive charge.

Where reconsolidation is employed to secure the charge in the device, access to each end of the cavity is usually required, and it is desirable that these access areas have a plane surface perpendicular to the center line of the explosive cavity.

Standardization

The standardization of the dimensions of explosive train components, especially diameters, tends to standardize loading operations and to reduce the number of different tools required. This factor is of particular significance to loading activities during wartime, when machine tool production capacity is inadequate to meet requirements.

Section 2.—Design of Tools and Equipment for Loading

General Considerations

Loading tools for various fuze explosive components are, in general, quite similar and follow, more or less, the same over-all pattern. They consist chiefly of a ram for compressing the charge, an anvil to support the charge, and a funnel which serves to guide the loose charge and the ram into the cavity being loaded. Where a cup is being loaded, support for the cup walls must be provided in most cases. Where the component is closed by crimping a cover disk into place, auxiliary tools are required for the performance of this operation.

The design of loading tools for explosive components requires careful consideration, particularly in view of the hazard associated with the loading operation. The important design factors are discussed in the following paragraphs.

Dimensional tolerances. Where a close fit is required, it must be uniformly close; where a loose fit is required, it must be uniformly

loose. Mercury fulminate and lead azide are examples of materials requiring close fits. Clearances varying from a slip fit (0.0004 inch) up to approximately 0.001 inch are used for these materials. Such clearances are necessary to prevent the explosive material from passing up around the ram with subsequent pinching and possible explosion. Tetryl is an example of a material requiring relatively loose fits because sticking of the ram is experienced if close fits are employed. Clearances for materials such as tetryl vary from approximately 0.001 inch for leads of one-eighth inch diameter to approximately 0.004 inch for booster pellets of the order of one inch or more in diameter. Gasless delay mixtures likewise are materials requiring relatively large clearances.

Loading pressures. The design of loading tools is influenced to a considerable extent by the pressures to be used in loading the particular components. Loading pressures commonly employed for the loading of fuze explosive components, except delay trains, vary between 10,000 psi and 20,000 psi. However, pressures no higher than 2500 psi are employed in some commercial loading operations. Where the tools are of a temporary nature, or where lower pressures are involved, lower quality steels or even non-ferrous materials may be employed. Copper or copper bearing alloys should not be used when loading lead azide because of the incompatibility between this explosive and copper bearing metals. Where pressures above 20,000 psi are used, a high quality material such as hardened class 5 tool steel is necessary for satisfactory results. Where long life of the tool is desired, class 5 tool steel, hardened and finely finished, is commonly prescribed even though the pressure may be no higher than 10,000 psi.

Finish of surfaces. It is important that all surfaces which come into contact with the explosive materials or with the explosive loaded component should have a high quality finish, about 8 (average depth of surface irregularities of 8 microinches) (ref. (1)) or better. The presence of blemishes allows explosive material to become lodged and to be subject to pinching or abrasion which might result in an explosion. Mars and scratches on surfaces in contact with explosive loaded components are conducive to sticking and might cause difficulty in removing the components from the tools.

Corners and joints. An important requirement in the design of loading tools is that the corners be sharp and true at the joints between different parts of the tool when the joints are in contact with the explosive material. Neither burrs nor radii can be tolerated at these locations, because radii or imperfections would allow the explosive material to flow into the cavities resulting from their presence, and subsequent pinching and explosion might result. The presence

of burrs offers the possibility of pinching or fracturing of crystals of explosive material, which might lead to an explosion. In the detonator loading tool shown in figure 10-1 for example, sharp corners are required on the end of the loading ram which contacts the explosive and at the bottom of the funnel ram guide which is recessed to accept the upper end of the detonator cup.

Loading for Experimental Purposes

Fuzes. The loading of explosive components for fuzes under development is a task which, for the most part, has not been adapted to mass production methods. For example, where detonators differing from standard production are required for such work, they are loaded singly in hand loading tools of simple, temporary, and oftentimes quite primitive design. Likewise, Navy fuze primers are frequently hand loaded and assembled singly. Figures 10-1 and

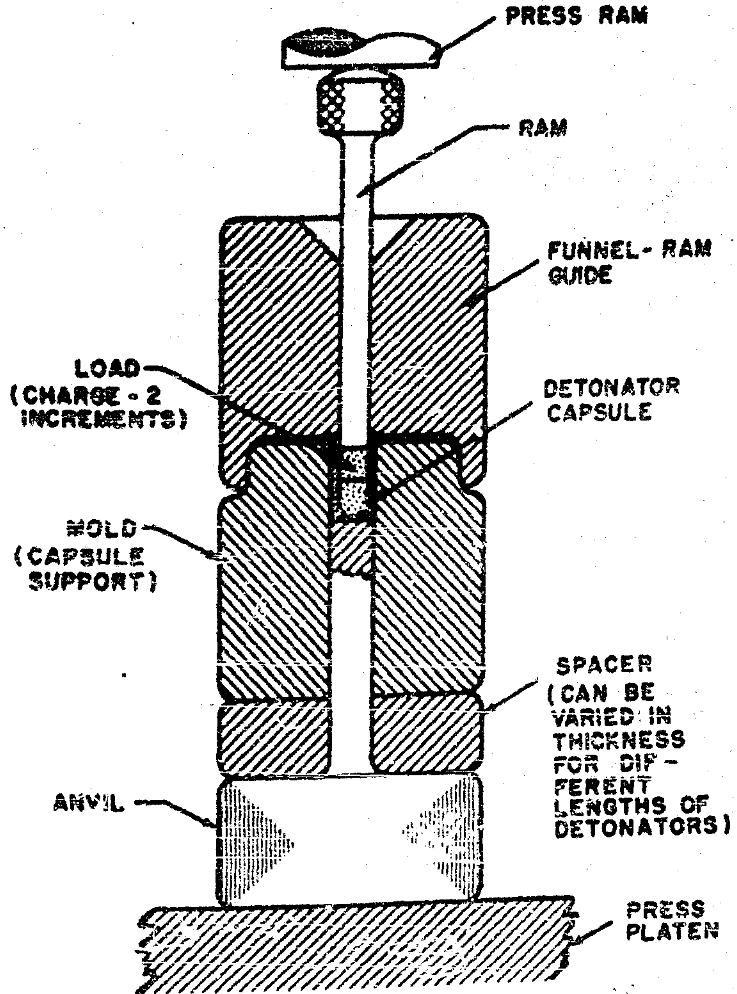

Figure 10-1. Experimental Hand Loading Tool for Detonators. Sectional View.

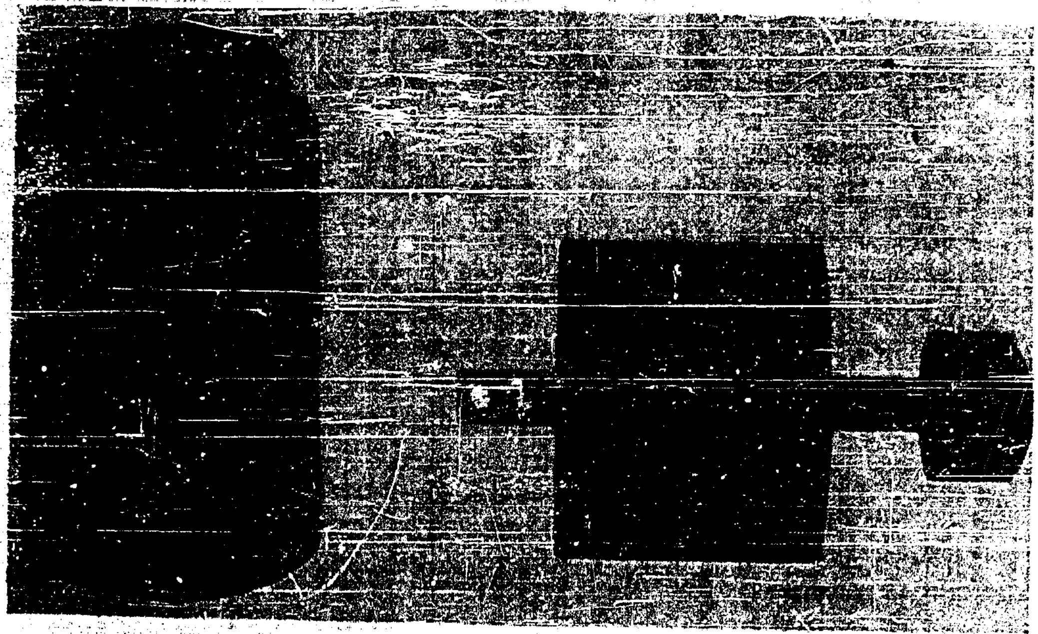

Figure 10–2. Experimental Hand Loading Tool for Detonators. Ram and Ram Guide Removed.

10–2 show a hand loading tool which is easily adapted to detonators of different lengths by interchanging parts.

Figure 10–1 shows the tool in cross section, with the detonator capsule and load (charge) in place during the consolidation process.

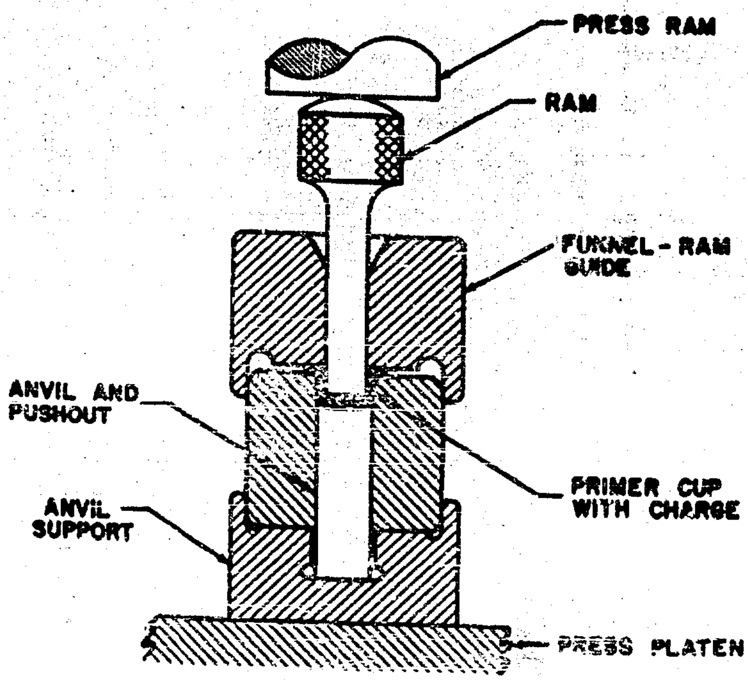

Figure 10–3. Primer Loading Tool for Mk 101 Type Primer. Sectional View.

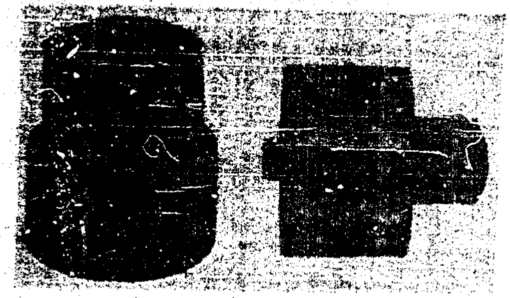

Figure 10–4. Primer Loading Tool for Mk 101 Type Primer.

Figure 10–2 shows the tool with ram and ram guide removed. The crimping rams (not shown) are similar to those shown in figure 10–16, which is a tool for production line use.

Figures 10–3 and 10–4 show a loading tool for primers, which is similar in design features to the detonator tool of figure 10–1. Because of the relatively small number of items required for experimental development, the durability of the materials used in tools for experimental loading need not always be the highest. Such tools are usually simple in design, even though they may be less convenient to use than tools designed for production purposes. Nevertheless, it should be emphasized that close tolerances and high grade finishes must be maintained because of the hazardous nature of the loading operation.

Leads and boosters. These components also, are loaded singly by hand methods, although for these items, high rates of production of tetryl pellets are obtained with automatic pelleting machines. Figures

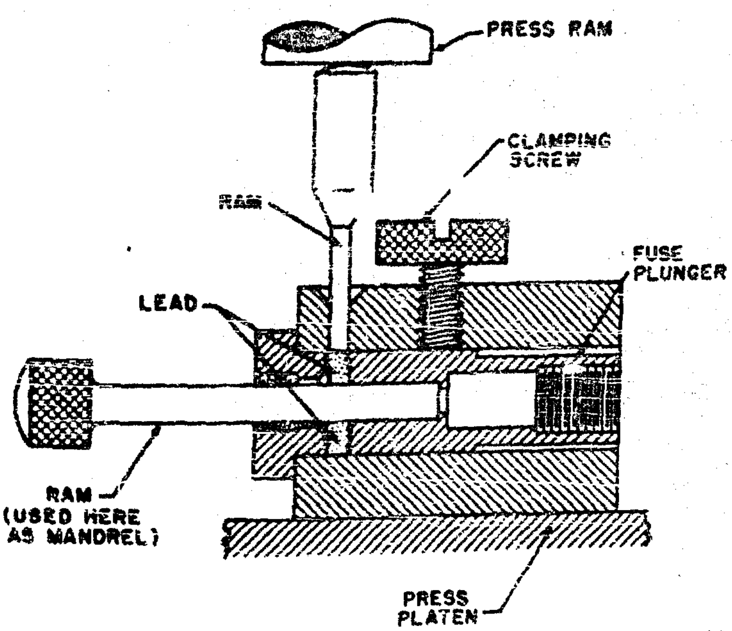

Figure 10–5. Hand Loading Tool for Leads. Sectional View.

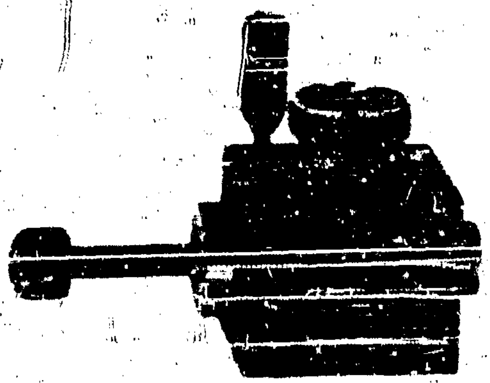

Figure 10–6. Hand Loading Tool for Leads.

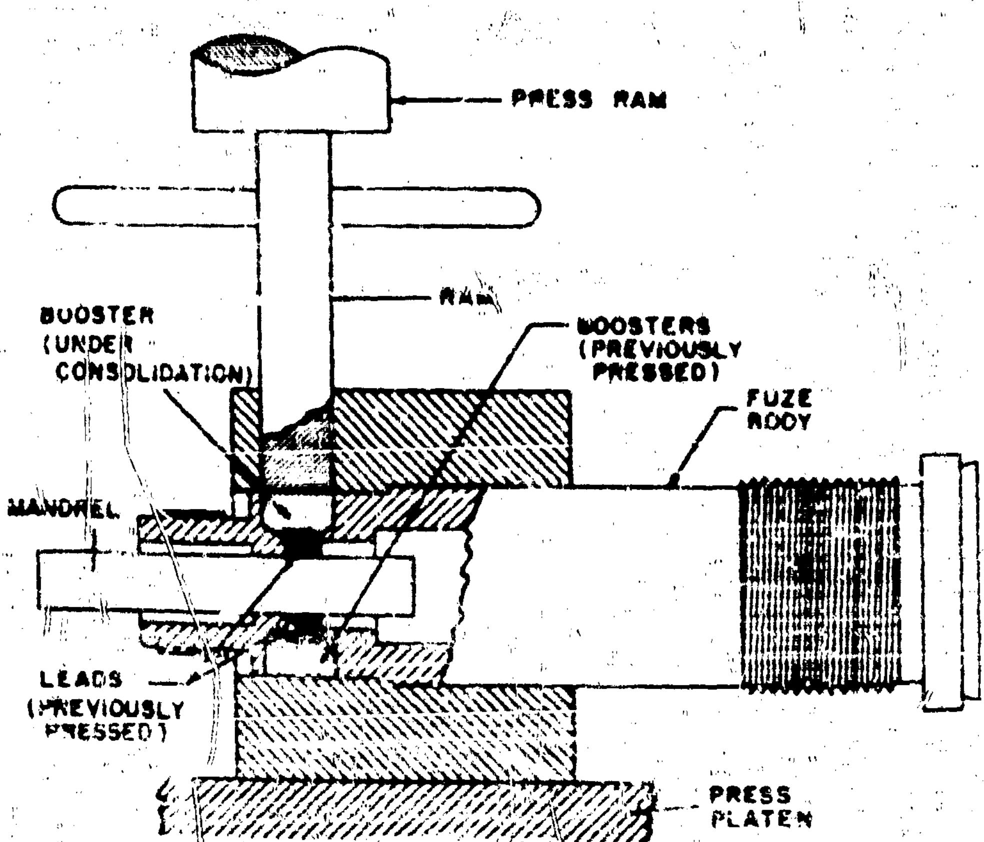

Figure 10–7. Hand Loading Tool for Boosters. Sectional View.

10-5 and 10-6 show a hand loading tool for leads, and figures 10-7 and 10-8 show a hand loading tool for boosters.

Fuze plungers. In some types of detonating fuzes a fuze plunger contains a detonator, a tetryl relay charge, and small detonating leads. The first operation in the loading of this plunger is to press the leads into place as previously described, with the tool in the position shown in figure 10-5. The tool is then set up so that the axis of the plunger is vertical, and the ram which was used as a mandrel for loading the leads is then used for the final crimping and placing of the detonator. The tetryl relay charge is then pressed into place with the same ram that was used in seating the detonator. Figures

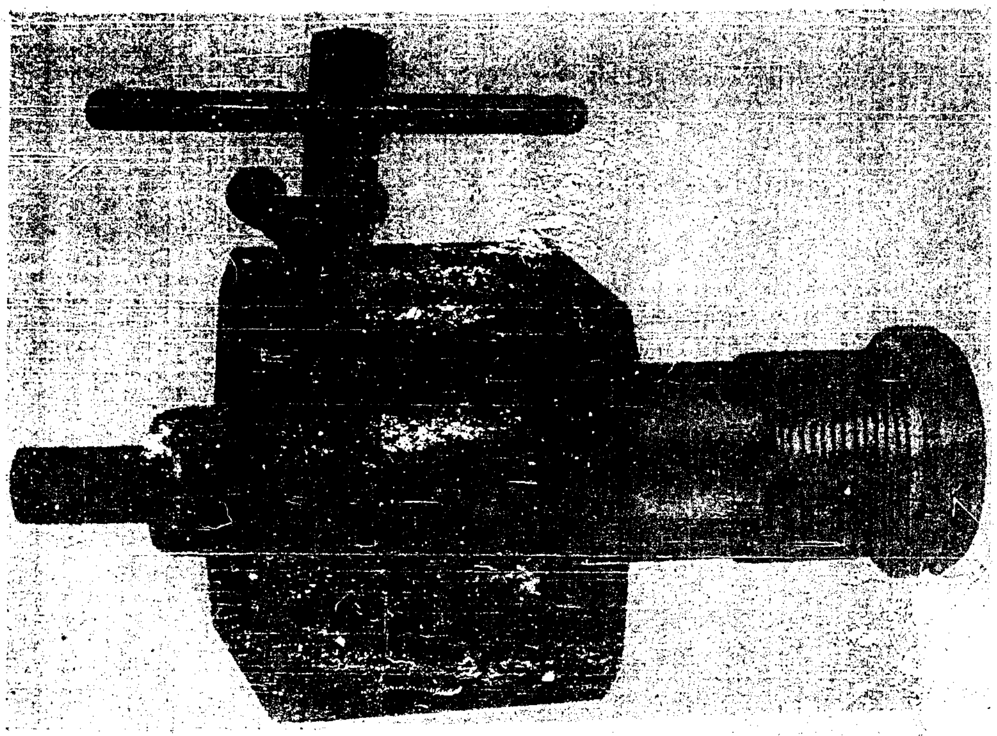

Figure 10-8. Hand Loading Tool for Boosters.

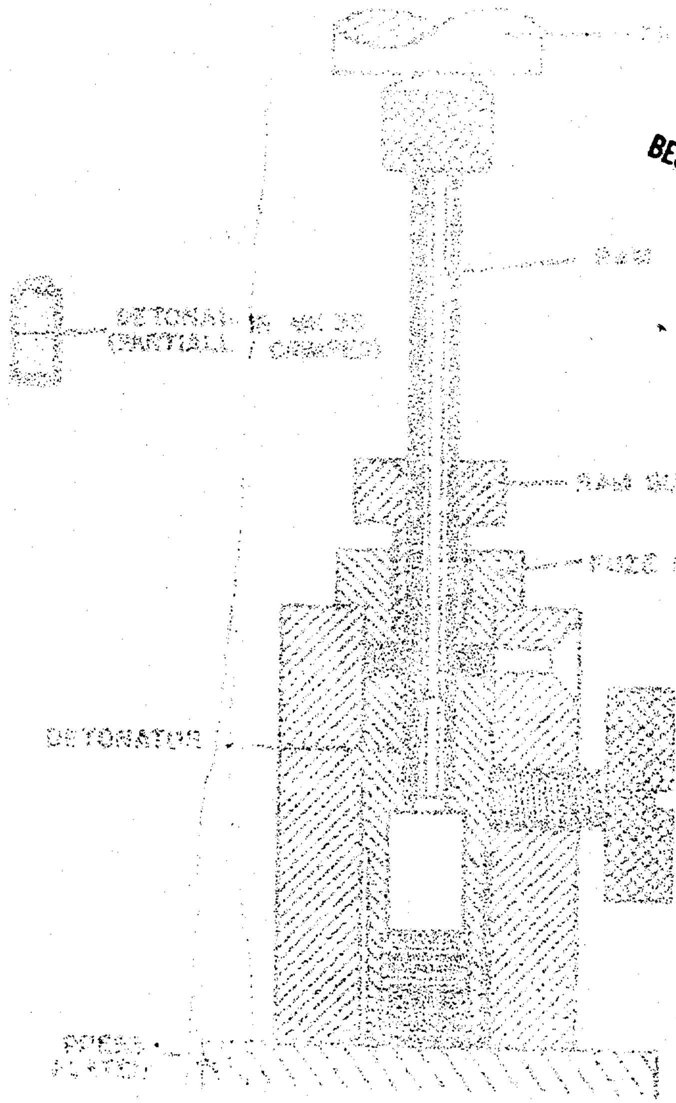

Figure 10-2. Tool for Assembling Detonator into Plunger.

[illegible] different sectional drawings of the same tool [illegible] the manner in which the tool is employed for these operations.

[illegible] elements. Tools for [illegible] delay elements [illegible] the same general pattern of tools already discussed for [illegible] components, that [illegible] the tools are in general designed for [illegible] loading [illegible], and the selection of materials from which they [illegible] governed by the same considerations.

[illegible] delay elements [illegible] in the tools a[illegible] comparable to those used for tetryl. For example [illegible] the delay element of the [illegible] Illuminating Projectile has a clearance between the loading ram and funnel of 0.00[illegible] inch for a diameter of approximately 0.2 inch. As in the case [illegible] tetryl, the relatively large clearances are necessary to prevent sticking of the pressing ram.

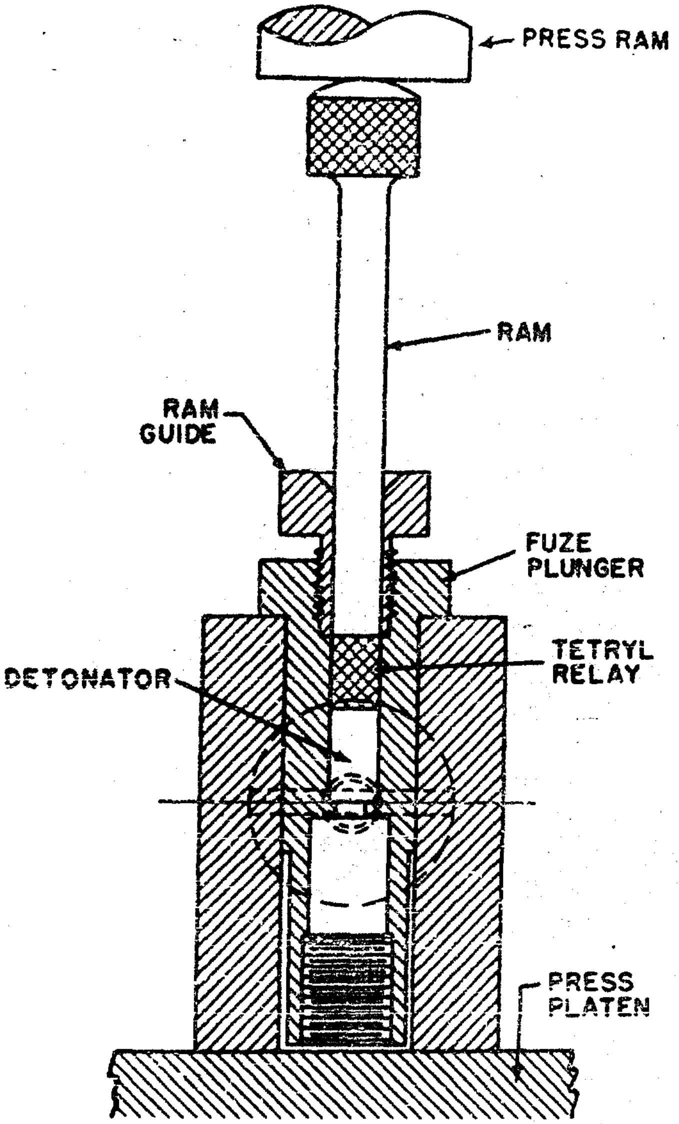

Figure 10–10. Tool for Loading Tetryl Relay Charge Directly into Plunger.

Black powder delay elements. In contrast to the tools for loading gasless delay elements, those for loading black powder delay elements have small clearances. Figures 10-11 and 10-12 show a tool designed for loading a black powder delay element for experimental purposes. This is a good example of a tool quickly and easily made for short run experimental loading. It is simple in design, yet suitable for loading delay columns of varying lengths. Its performance is excellent, even though it is made of easily worked materials and its fabrication required only a few man-hours.

Electric primers and detonators. Tools for loading the components of electric primers and detonators, which consist primarily of consolidated explosive charges in capsules, are comparable to the loading tools for other similar components such as detonators and capsule encased [illegible]. One noteworthy example of a special operation is the loading of the wet, hot-wire ignition charge of the Mk 113 type electric primer simply by buttering it into place with a small spatula.

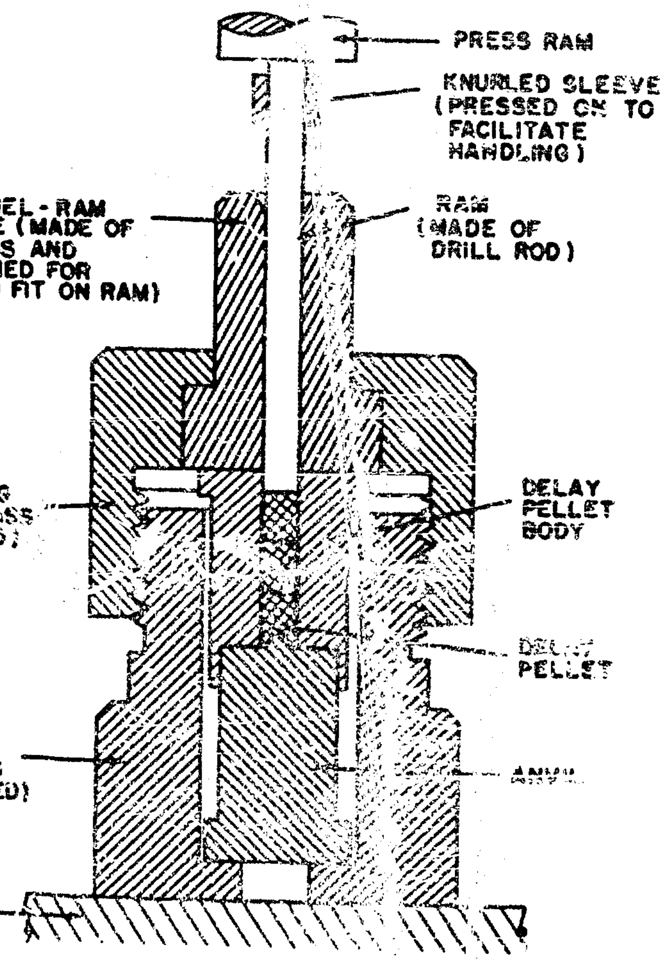

Figure 10-12. Tool for Experimental Loading of Black Powder Delays. Sectional View.

Figure 10–12. Tool for Experimental Loading of Black Powder Delays.

Loading for Production

Production-line technique. Production loading is frequently and conveniently accomplished by the so-called "production-line" technique using hand tools, in which each individual of a group loading a particular component performs a single operation and passes the tool and component on to the next individual of the "line." Thus the component moves along and emerges from the end of the line in the finished state. For this technique, more tools are required than there are individuals or operations in the group, and there is a continuous movement of the tools along the line and back to the station for the initial operation.

Figures 10–13 and 10–14 show a tool for this type of loading. The process requires four stations (or operations): (1) weighing and introduction of the loose powder into the funnel; (2) application of proper

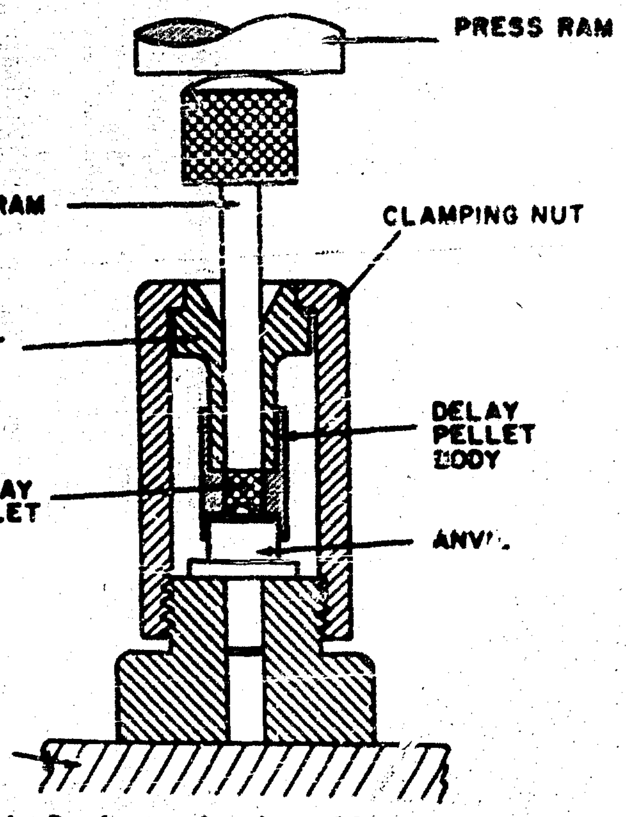

Figure 10-13. Tool for Production Loading of Black Powder Delay Element. Sectional View.

Figure 10-14. Tool for Production Loading of Black Powder Delay Element.

pressure to the ram; (3) disassembly of tool and removal of completed delay component; (4) cleaning and return of tool to station 1.

From the standpoints of tool life and product quality, it is desirable that this tool be made of good materials and to high standards of workmanship. For example, the tool used for loading the delay element for the Navy projectile fuze Mk 29 is made of class 5 tool steel, and the clearance between ram diameter and ram guide is initially 0.0004 inch with the finish 8 or better. The finish improves with use because of the burnishing process. A probable replacement of the ram and ram guide would need to be made when clearance has increased to 0.0[illegible] inch.

Figure 10–15 shows a detonator loading tool design considered satisfactory for quantity loading by means of the production-line technique. Comparing this design with that shown in figures 10–[illegible]

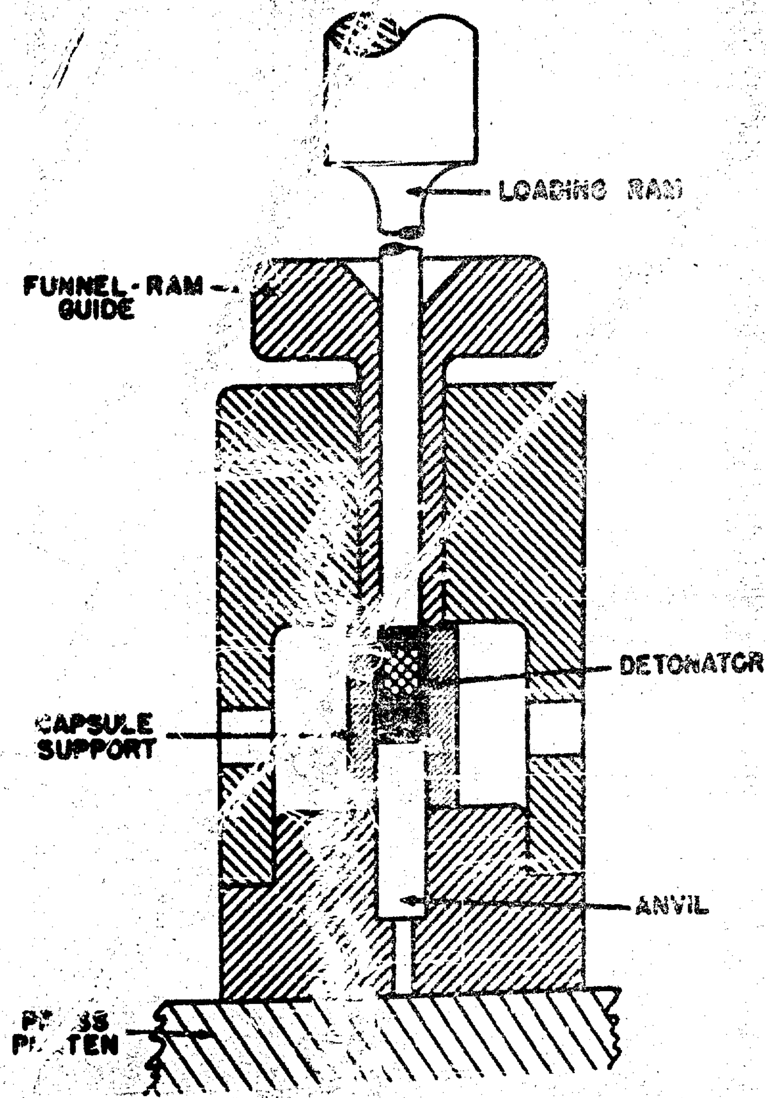

Figure 10–15. Loading Tool for Detonator.

and 10–2, a decided similarity between hand tools for production and experimental loading will be noted. Figure 10–16 illustrates, primarily, the crimping and "knockout" features of the tool, thus, the charging and pressing operations of this three-increment detonator are omitted in the figure. For the final or knockout operation, the sleeve containing the detonator is removed from the original base and placed on one that permits passage of the detonator. In the use of this tool for loading a three-increment detonator, it is convenient to use eight stations: three weighing stations, three pressing stations, one common crimping and knockout station, and one cleanup and tool reassembly station.

Hand loading tools. As noted earlier in this chapter under the topic Loading for Experimental Purposes, hand loading tools are much used for peacetime loading of Navy fuze primers. Tools of

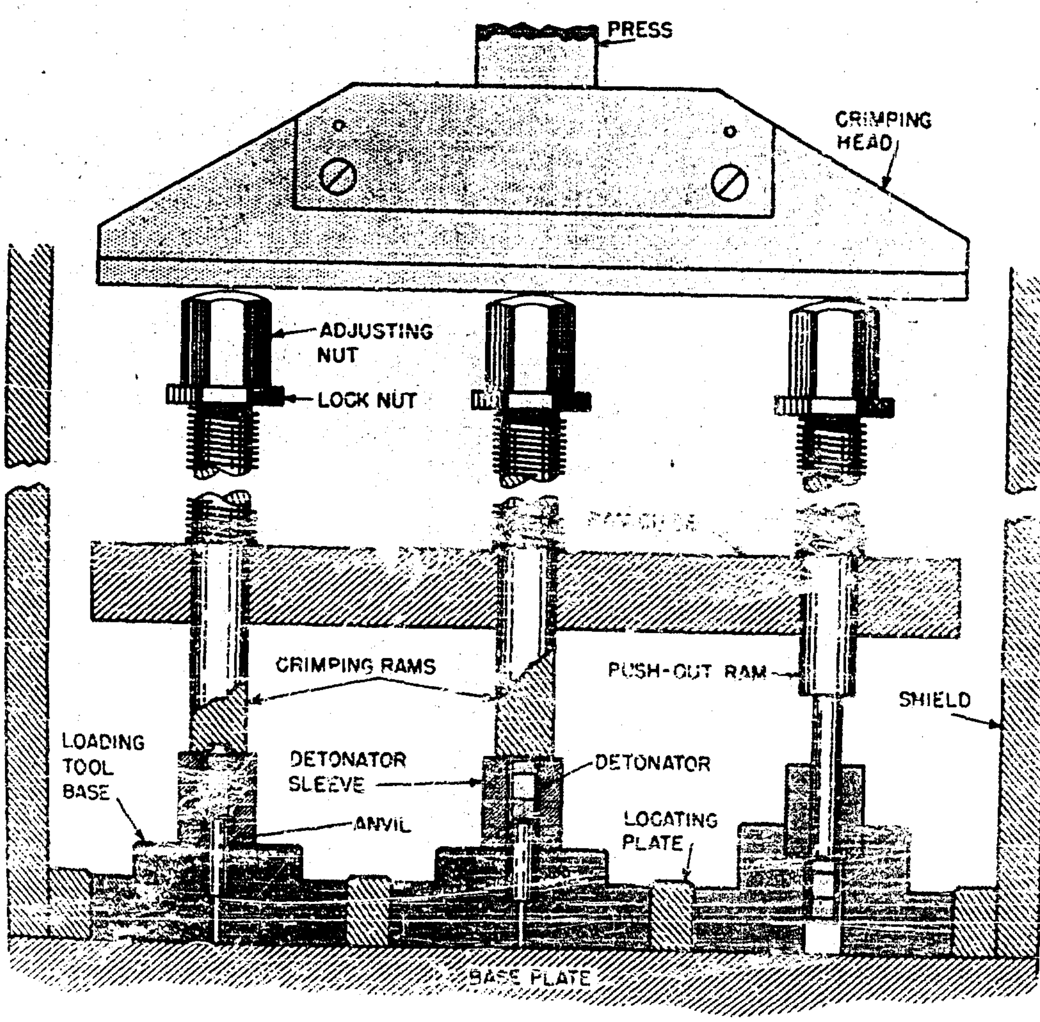

Figure 10–16. Crimping Tool for Detonator.

similar types are used in ordnance development activities for experimental purposes and in ordnance plants for production purposes. However, only dry mixtures are loaded in this manner.

Charge-plate method. The commercial technique used for loading primers of the type used in fuzes involves the charging of primers by the "charge-plate" method. This method consists of the following operations. Holes in a charge plate, sized to the correct volume to hold the required amount of explosive, are charged with priming mixture (usually dampened to lessen the hazard). The charge plate is then placed over a similar plate containing the primer cups so that the holes in the two plates are aligned. The priming mixture is then transferred from the charge plate to the primer cups by means of a knockout plate which is placed over the charge plate. The knockout plate, which has a ram aligned with each hole in the charge plate, is then depressed, thus knocking each charge into its respective cup. Consolidation is accomplished on a press which actuates a set of rams (frequently ten) operating as a gang. Each ram also serves to punch a paper disk as the ram advances to consolidate the charge. The disk serves to prevent the wet charge from adhering to the ram. The consolidating pressure is controlled by a spring under each ram.

The loading of the Mk 36 Detonator during World War II affords an interesting example of production loading. The design of this detonator is such that the cup diameter and length are nearly equal (0.295 inch by 0.280 inch, respectively). Accordingly, loading is adaptable to primer production loading techniques, and the detonator was loaded in multiple by the charge-plate method. The dry charge, consisting of an increment of tetryl and an increment of lead azide, was introduced and consolidated in two separate operations. Then the caps were removed from the plate and hand crimped indiviaually.

Wet loading technique. A special loading tool designed by the Naval Ordnance Laboratory for loading primers Mk 101 in small groups by the wet loading technique is shown in figures 10-17, 10-18, and 10-19. The tool is similar to the commercial production loading tools but does not have individual pressure control on each primer. However, because of good control of dimensions, variations in pressure experienced are not sufficient to affect the primer performance appreciably. A load of ten thousand pounds on the cover plate gives an average of five hundred pounds on each of the twenty primers accommodated by this tool. Figure 10-17 shows the assembly just after transferring the charge from the charge plate to the primer cups, a hand operation. Figures 10-18 and 10-19 both show the

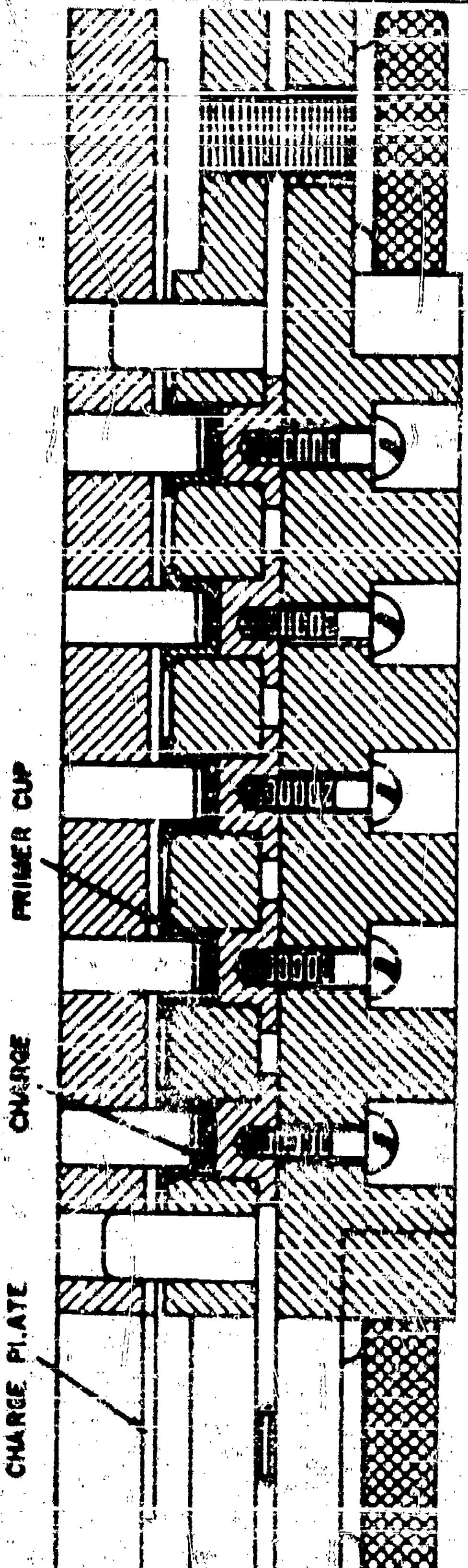

Figure 10-17. Primer Charge Transfer Operation.

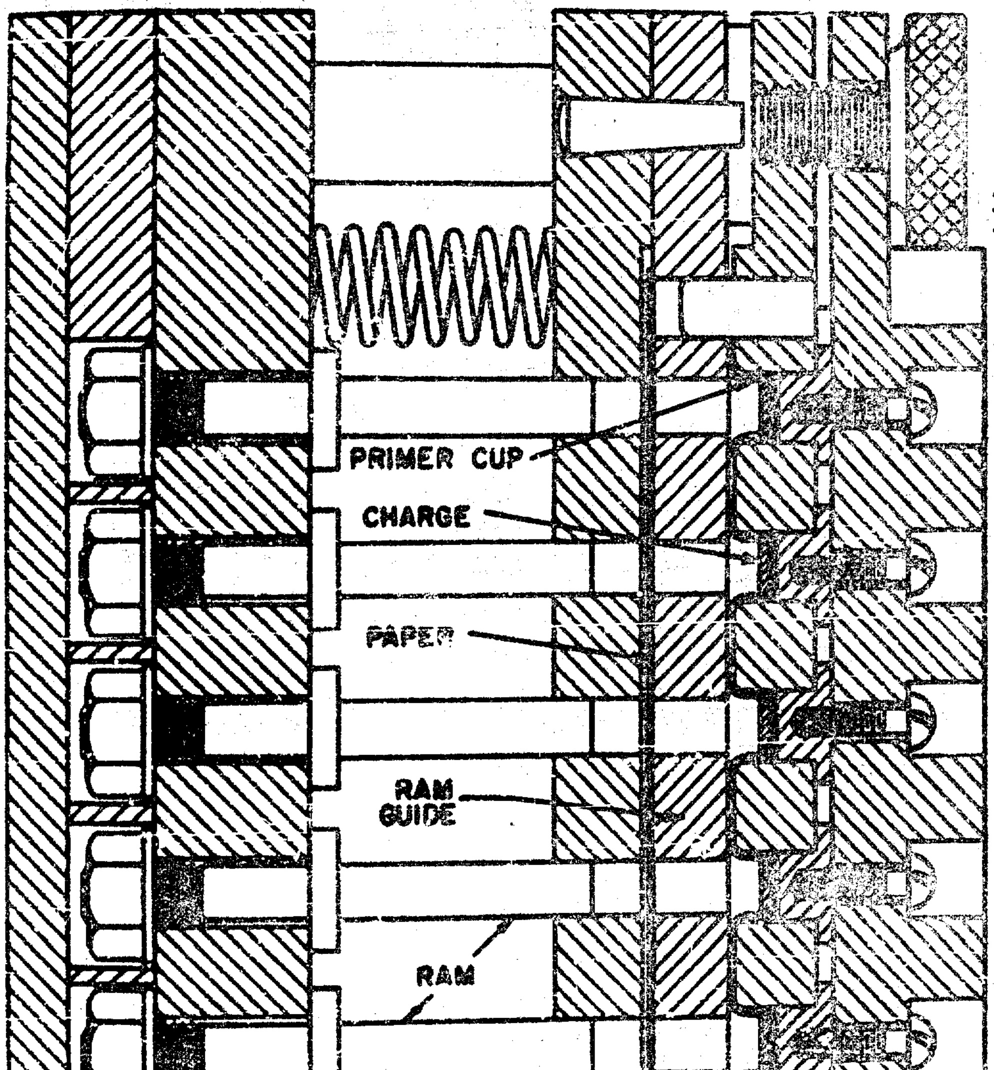

Figure 10–18. Primer Wet-Loading Tool, Semi-Production Type. Sectional View.

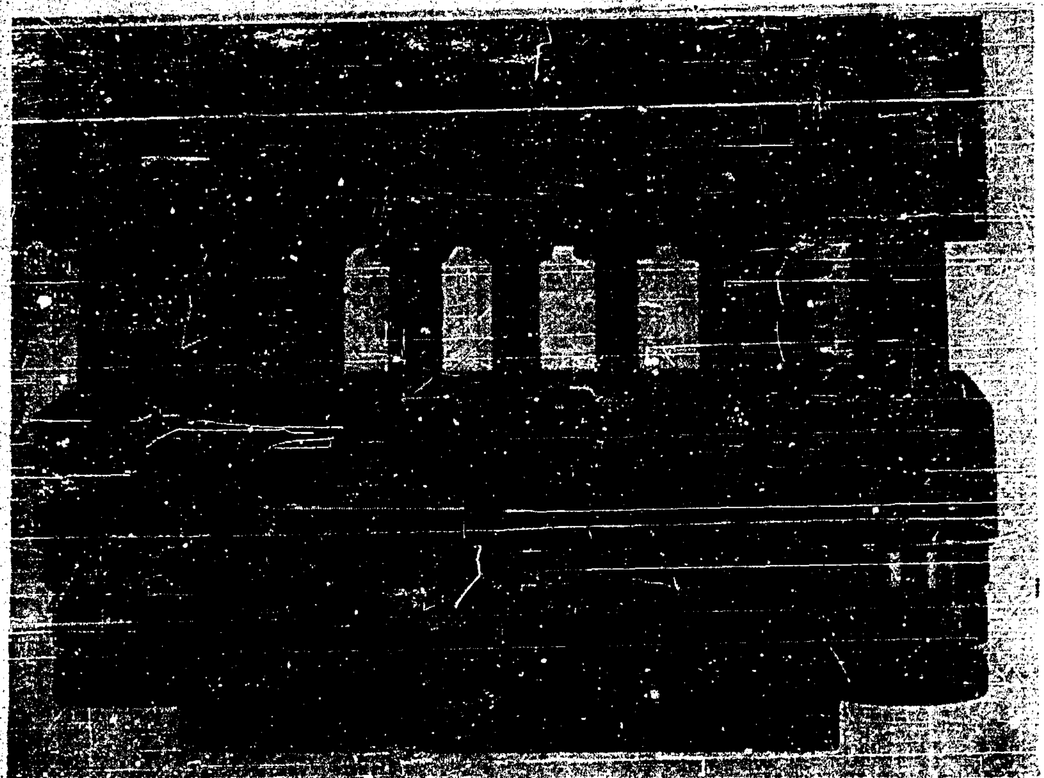

Figure 10–19. Primer Wet-Loading Tool, Semi-Production Type.

tool assembly ready for paper disk punching and charge consolidation, a press operation. This tool is adaptable to quasi-production in experimental development of primers where substantial numbers of a given item are required for statistical studies.

Jones machine. During World War II, a detonator loading machine developed by the R. A. Jones Company of Covington, Kentucky was used for the production of various explosive components such as detonators, stab primers, and encased leads. The machine is semiautomatic in operation, the number of operating personnel varying in accordance with the item under production. The following example of its production capacity is cited. When used for loading the detonator Mk 33, this machine gave a daily output of 10,000 detonators, with five operators and one runner. An average of three percent of the output was unsatisfactory. By the use of hand-loading techniques, 30 operators and 1 runner could produce 3,000 detonators Mk 33 daily. In this instance, the Jones machine showed an advantage of about 16 to 1 from the standpoint of detonators produced per man-hour. The consensus is that for a

comparable amount of supervisory effort, the machine loaded components are more satisfactory than those loaded by hand. Figure 10-20 shows the Jones machine in operation, the operators, and an inspector making a final check on the production. Figure 10-21 shows the sequence of operations in a three-increment detonator of the type shown in cross section on the same figure.

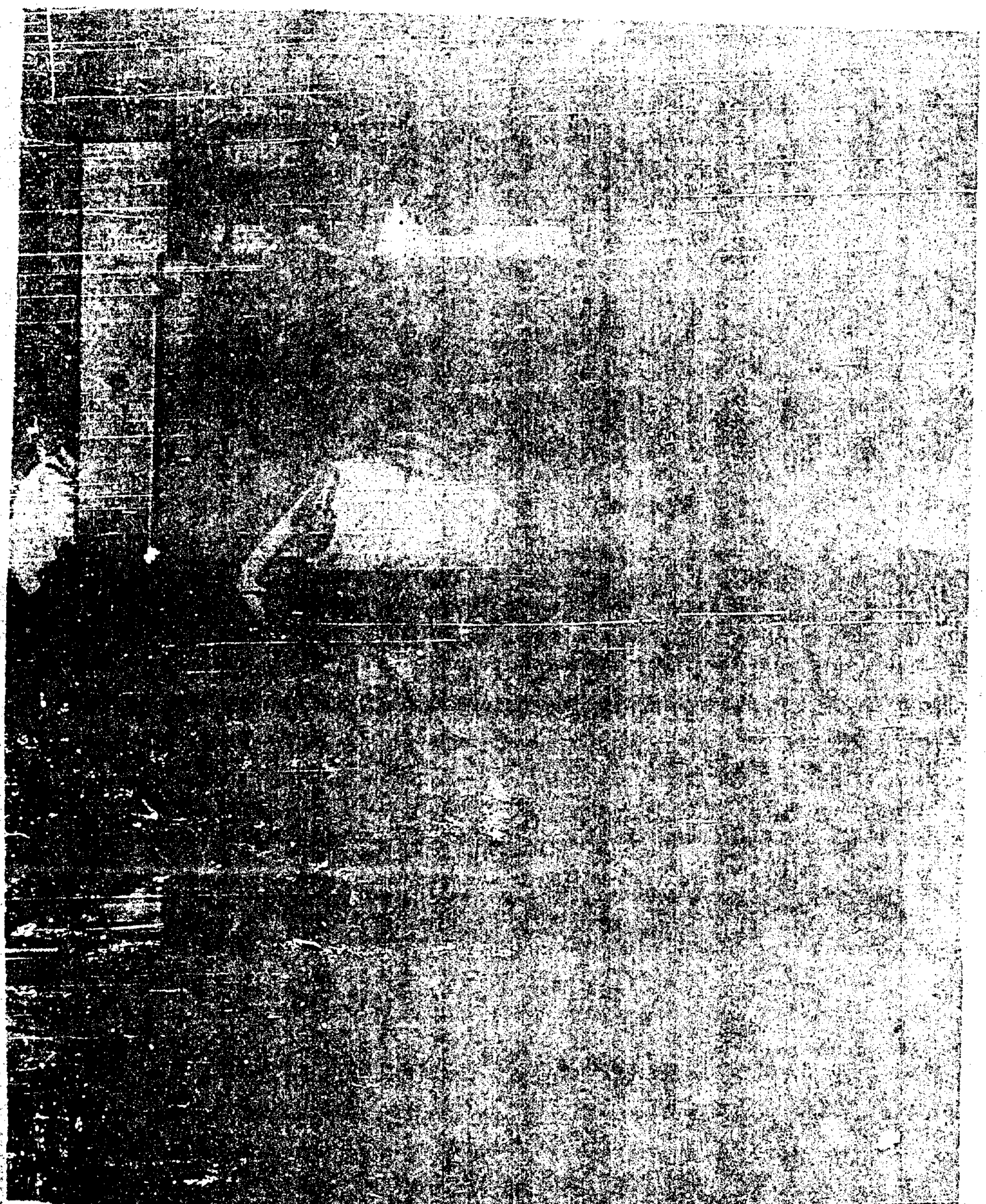

Figure 10-20. Semi-Automatic Detonator Loading Machine.

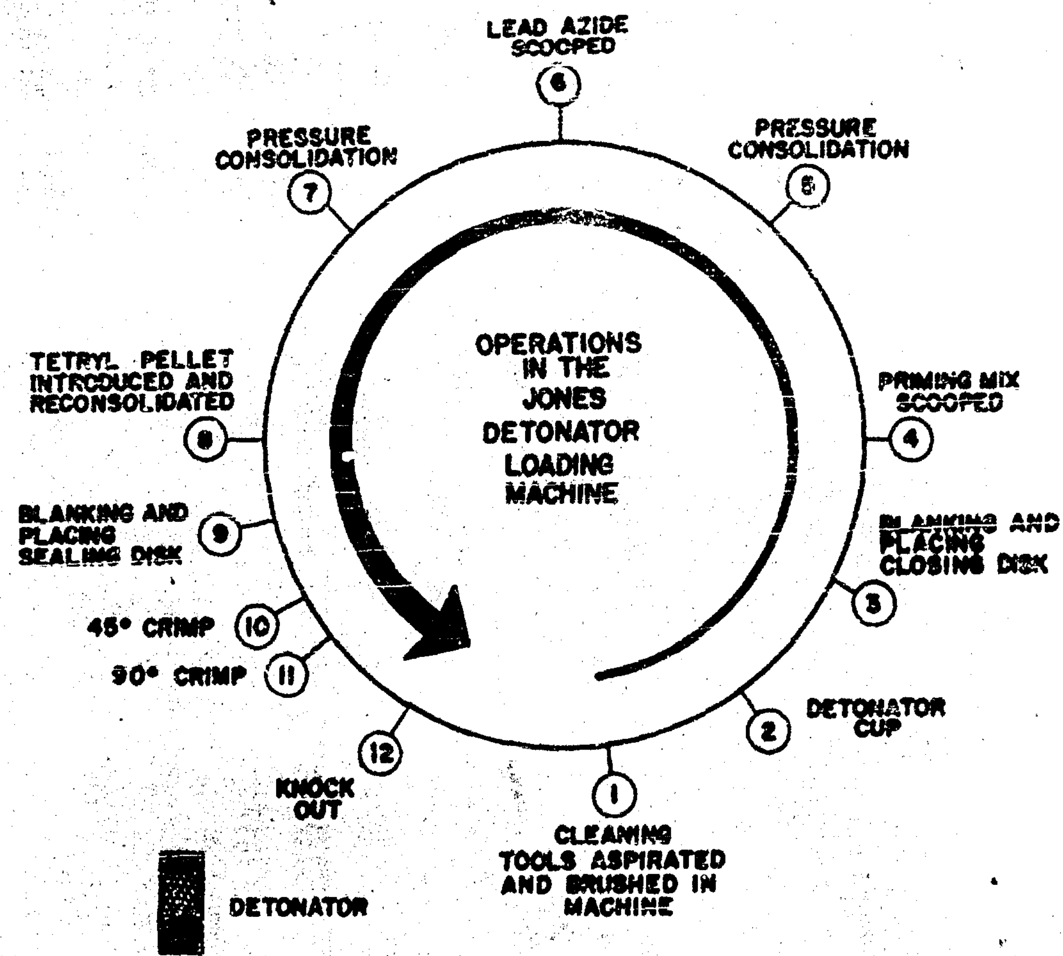

Figure 10–21. Sequence of Operations, Semi-Automatic Detonator Loading Machine.

Loading of leads. The production loading of leads is accomplished by many techniques and depends to some extent on the design of the particular lead being loaded. Hand loading of loose powder or the reconsolidation of preformed pellets is conducted with tools similar in design to those previously described. Frequently the pellets for leads, as well as boosters, are formed on automatic pelleting machines. Figure 10–22 shows the type of automatic pelleting machine used by the Navy for forming tetryl pellets. These pelleting machines are manufactured in a wide variety of sizes, are quite versatile, and can be used for the rapid production of various sizes of pellets. They are entirely automatic in operation. As already noted, cased leads, as well as detonators, may be loaded in the Jones detonator machine just described.

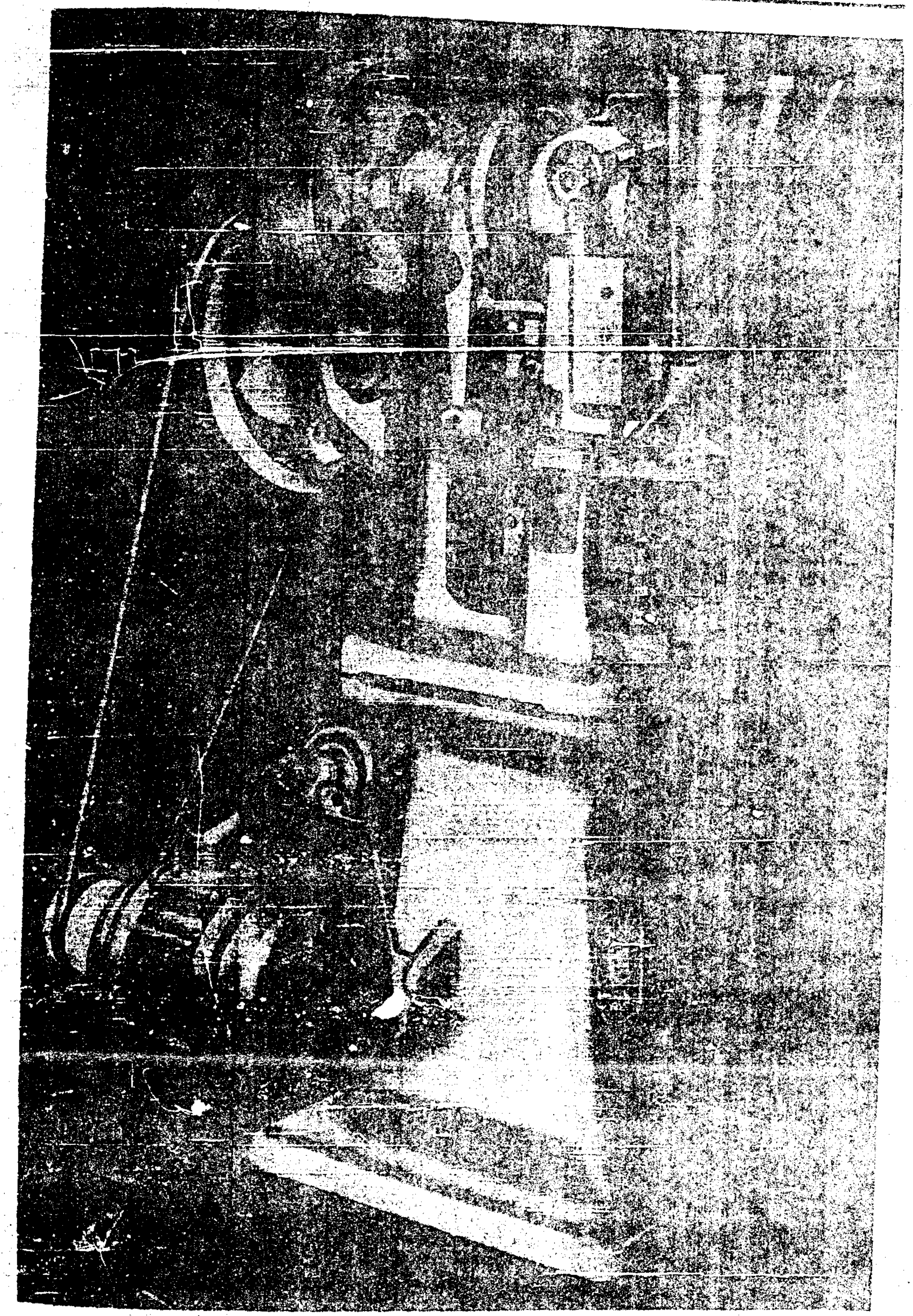

Figure 10–22. Automatic Pelleting Machine.

Loading of boosters. Two types of booster design are used in fuzes. In one type, the booster cavity is charged by the pressing of loose tetryl or the reconsolidation of preformed tetryl pellets. In the second type, tetryl pellets are formed so as to make a neat fit in the booster cavity and are secured in place rather than reconsolidated. Motion of pellets which are not reconsolidated is prevented by placing padding in the booster cavity. Loading tools for the type of booster which contains the tetryl pressed into place are the same as, or similar to, those described under Loading for Experimental Purposes (page 10–5). When the pelleting press is used for forming the tetryl pellet, a loading tool is not required for the type of booster in which a tetryl pellet is secured in the booster cavity without reconsolidation.

Loading of black powder delay elements. Hand tools for the production loading of black powder delay elements are similar to, or the same as, those for experimental loading. However, the prepelleting and reconsolidation of black powder charges in delay cavities is practiced and found to be advantageous.

Loading of gasless delay elements. Tools for the production loading of gasless delay elements are similar to, or the same as, those for experimental loading. Available data indicate that all gasless delay elements are loaded manually; accordingly, the differences between experimental and production tools lie in the durability of the materials from which they are made and in the refinement of certain details.

Methods of Segregating the Correct Quantity of Material

In practically all experimental loading, the quantity of charge is measured gravimetrically on a balance. Where charge weights do not exceed 250 milligrams, the Roller-Smith balance, shown in figure 10–23, has been found to be a very convenient instrument. For larger charges, a pulp balance is convenient.

In production loading both gravimetric and volumetric methods are used for the segregation of the proper quantity of charge. For the gravimetric segregation of small quantities, the Roller-Smith balance, just mentioned, is the most convenient. In the production loading of small quantities of dry materials, volumetric methods are usually employed. A convenient and frequently practiced method is to use a scoop having a capacity equal to the volume required to give the correct weight. The explosive being measured is scooped to overflowing from a container of the material, and the surplus rejected by drawing the scoop under a stretched band of rubber or similar material.

Figure 10–23. Balance for Weighing Small Charges.

By this means the quantities of material being loaded can be controlled accurately.

As previously noted, quantity segregation in the charge-plate method of loading primers involves filling holes of the correct volume in the charge plate. A wet mixture is usually used with this method of loading. The mixture is rubbed into place with a special type of rubbing tool. Considerable experience is necessary for the operator to learn the proper rubbing action and pressure to give the correct amount of explosive in the holes and to give uniformity of quantity in all the holes in the plate.

Volumetric segregation is also provided on the automatic pelleting machine. Here the volume is controlled by the depth of cavity for the material being pelleted, since the feed cup always sweeps the charge flush with the surface at the top of the cavity.

Section 3.—References

(1) MIL-STD-10, **Surface Roughness, Waviness, and Lay.** Munitions Board Standards Agency, National Military Establishment, August 2, 1949.

GLOSSARY OF TERMS USED IN ORDNANCE EXPLOSIVE TRAIN DESIGN

(Definitions marked with an asterisk have been approved by the JAN Fuze Committee. The Committee's definitions are indicated by quotation marks.)

Booster Charge*—"The final high explosive component of an explosive train which amplifies the detonation from the lead or detonator so as to reliably detonate the main high explosive charge of the munition." Also used loosely to indicate a reinforcing or augmenting charge.

Bore Premature—The explosion of a gun-launched projectile in the barrel.

Brisance—The capacity of an explosive to shatter any confining medium.

Brisant—Sudden, sharp, violent. A descriptive term which when applied to explosions indicates a powerful impulse of short duration.

Creep—A term used to designate the forward movement of components with respect to the projectile that tends to take place in flight as a result of the force caused by deceleration due to air resistance.

Dead Pressed—In an explosive, a highly compressed condition which tends to prevent the transition from deflagration to detonation that would otherwise take place.

Deflagration—A burning in which the velocity of the advance of the flame front is less than the velocity of sound in the material. In this case, heat is transferred from the reacted to the unreacted material by conduction and convection.

Delay*—"An explosive train component which introduces a controlled time delay in the functioning of the train."

Delay Element—An explosive train component normally consisting of a primer, a delay column, and a relay detonator or transfer charge assembled in that order in a single housing.

Detonation—A chemical reaction in which the reaction front advances with a speed which exceeds the velocity of sound in the material. In this case, energy is transmitted from the reacted to the unreacted material by a shock wave.

Detonation, Low Order—A chemical reaction in a detonatable material in which the reaction front advances with a velocity which is appreciably lower than that which is the characteristic detonation velocity for the material in question.

Detonator*—"An explosive train component which can be activated by either a non-explosive impulse or the action of a primer and is

capable of reliably initiating high order detonation in a subsequent high explosive component of the train. When activated by a non-explosive impulse, a detonator includes the function of a primer. In general, detonators are classified in accordance with the method of initiation; such as percussion, stab, electric, friction, flash, chemical, etc."

Dud—An explosive loaded item that fails to explode when subjected to treatment that should cause it to function.

Dwell—In press loading powders into cavities, the interval of time that the powder is held at the full loading pressure.

Exploder—An alternative term for a fuze, usually used in connection with torpedoes.

Explosive Train*—"An arrangement of a series of combustible and explosive elements consisting of a primer, a detonator, a delay, a relay, a lead and booster charge one or more of which may be either omitted or combined. The function of the explosive train is to accomplish the controlled augmentation of a relatively small impulse into one of sufficient energy to cause the main charge of the munition to function."

Filler—The explosive material which comprises the main charge in an explosive loaded ordnance item.

Flash—Refers to the method of initiating an explosive loaded element by heat or flame from another element.

Flash Charge—A readily ignitable explosive charge used in ignition elements of electric primers and detonators. Its function is usually to ignite a subsequent charge of lesser sensitivity and greater brisance.

Fuse—A tube or cord filled or impregnated with combustible matter for igniting an explosive charge after a predetermined interval.

Fuze—A device designed to achieve functioning of an explosive loaded ordnance item at the desired time.

Fuze Explosive Train*—See Explosive Train.*

Gun Primer—A device used to ignite gun propellant. It usually consists of an ignition element, a black powder booster charge, and an extender tube filled with black powder. In smaller calibers it may resemble a fuze primer.

Hermetic—Made impervious to air and other fluids as by metal fusion.

High Explosives——Metastable materials that are relatively insensitive to heat or impact and that when properly initiated have detonation velocities higher than about 4000 meters per second. Examples are Tetryl and TNT.

High-order—When pertaining to reaction rates as in detonations and deflagrations, the term "high-order" indicates the highest stable

rate of advance of reaction front of which the material is capable under the prevailing conditions.

Impetus—The work that an explosive is capable of performing usually quoted as ft. lb. per lb. of explosive.

Input Characteristics—The characteristics of an explosive component which determine its sensitivity to initiation by externally applied energy.

Interrupter—A fuze or exploder component that interrupts the explosive train when the device is in the unarmed condition, and that moves during arming in such a way as to render the explosive train operative.

Lead*—"An explosive train component which consists of a column of high explosive, usually small in diameter, used to transmit detonation from one detonating component to a succeeding high explosive component. It is generally used to transmit the detonation from a detonator to a booster charge."

Lead-in—An explosive lead that conducts a detonating impulse into an explosive loaded cavity.

Lead-out—An explosive lead that conducts a detonating impulse out of an explosive loaded cavity.

Low-order—When pertaining to chemical reaction rates as in detonations and deflagrations, the term "low-order" indicates a slower rate of advance of reaction front than the material is capable of supporting.

Munroe Effect—See Shaped Charge.

Obturate—To stop or close an opening so as to prevent escape of gas. To seal as in delay elements.

Output Characteristics—The characteristics of an explosive component which determine the form and magnitude of the energy released when the component functions.

Percussion—Refers to the method of initiating an explosive loaded item by a sudden pinching or crushing of the explosive material, as between a blunt firing pin and an anvil.

Pressure Dwell—See Dwell.

Primary Explosives—Metastable materials that are very sensitive to initiation by impact or heat. Examples are mercury fulminate, lead azide, and lead styphnate.

Primer*—"A relatively small and sensitive initial explosive train component which on being actuated initiates functioning of the explosive train and will not reliably initiate high explosive charges. In general, primers are classified in accordance with the method of initiation; such as, percussion, stab, electric, friction, chemical, etc."

Pyrotechnic Composition—A mixture of materials consisting essentially of an oxidizing agent (oxidant) and a reducing agent (fuel). It is capable of reacting if heated to its ignition temperature.

Relay*—"An element of a fuze explosive train which augments an outside and otherwise inadequate output of a prior explosive component so as to reliably initiate a succeeding train component. Relays, in general, contain a small single explosive charge such as lead azide and are not usually employed to initiate high explosive charges."

Rotor—See Interrupter.

Sensitivity—See Input Characteristics.

Setback—Movement of components of a missile, relative to the missile as a whole, that results from the force due to acceleration during launching.

Shaped Charge—An explosive charge shaped to make possible the concentration of the explosive force in the desired direction. The result is called the Munroe Effect.

Shutter—See Interrupter.

Slider—See Interrupter.

Squib—A small electrically actuated initiator.

Stab—Refers to a method of initiating explosive loaded items by piercing (pricking) with a pointed firing pin (needle).

Surveillance—Stowage or storage under observed conditions.

Surveillance Test—A study of useful life characteristics under controlled or observed storage conditions.

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